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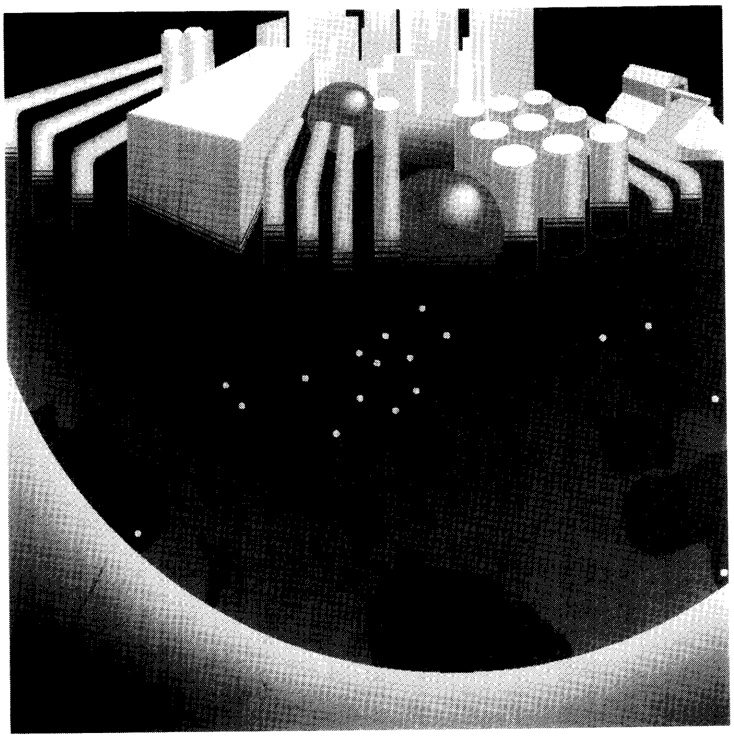
Quality Energy Efficiency Retrofits for Wastewater Systems



STATE OF CALIFORNIA
ENERGY COMMISSION

Quality Energy Efficiency Retrofits for Wastewater Systems

CR-109081
P400-98-013

Final Report, December 1998

EPRI Project Manager
Keith Carns

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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ORGANIZATION(S) THAT PREPARED THIS REPORT

HDR Engineering, Inc.
ENTEG, Inc.
Black & Veatch, LLP

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523, (510) 934-4212.

CITATIONS

This report was prepared for the EPRI Municipal Water and Wastewater Program by

HDR Engineering, Inc.
Folsom, CA

ENTEG, Inc.
Irvine, CA

Black & Veatch, LLP
Kansas City, MO

California Energy Commission
Carrie Anderson, Project Manager

This report describes research sponsored by the EPRI Community Environmental Center and the California Energy Commission.

This report is a corporate document that should be cited in literature in the following manner:

Quality Energy Efficiency Retrofits for Wastewater Systems, EPRI, Palo Alto, CA: 1998. CR-109081.

REPORT SUMMARY

This manual is targeted to the operations and engineering staffs of wastewater treatment facilities. It is intended to be used by them as a guide to retrofitting energy saving equipment into their plants.

Background

Operations and engineering staff in wastewater treatment plants are constantly engaged in the process of improving their operational efficiency. There are two basic ways to achieve this:

- Retrofits (equipment changes or additions)
- Operational modifications

This manual deals primarily with retrofits.

Objective

Electric utility representatives who have read this manual will be more informed and better prepared when discussing retrofit projects with their customers.

Approach

Energy costs at wastewater treatment facilities can be reduced by several different methods:

- Shifting electrical loads to reduce peak demand
- Process changes
- Improving equipment efficiency

Successful retrofit projects involve a number of steps, including understanding motor systems, conducting an energy assessment, designing and selecting equipment, installing and maintaining the equipment, and documenting energy cost savings.

Funding is one of the major obstacles for energy retrofit projects. However there are many different kinds of financing available. One type of financing that is becoming increasingly popular is electric utility-sponsored financing programs. Performance contracting, where contractors are given a portion of the energy cost savings by energy service companies, are another option.

EPRI Perspective

EPRI's Municipal Water and Wastewater Program was created to help member utilities address the energy needs of the more than 60,000 water systems and 15,000 wastewater systems in the United States. These facilities are among the country's largest energy consumers, requiring an estimated 75 billion kWh nationally, about 3% of the annual U.S. electricity use.

Safe drinking water and effective wastewater treatment are vital services needed in all communities. These safeguards protect the public health, strengthen the community infrastructure, and provide a foundation for economic growth. In collaboration with the California Energy Commission, EPRI's Municipal Water and Wastewater program produced this report to help its utility members understand retrofit projects that can increase the efficiency of wastewater treatment plants. It is a companion to *Quality Energy Efficiency Retrofits for Water Systems* (CR-107838).

CR-109081

Interest Categories

L3004 Municipal Water & Wastewater
E3003 Waste and Water Management

ACKNOWLEDGMENTS

EPRI Municipal Water and Wastewater Program Technical Applications and Services Committee

Dave Visintainer, City of St. Louis Water Department, Committee Chair
David Perkins, Perkins Engineering, Committee Co-Chair
Carrie Anderson, California Energy Commission, Project Manager

Special thanks go to the numerous individuals who devoted their time and technical expertise to contribute to this guidebook:

Carrie Anderson
California Energy Commission

Franklin L. Burton
Burton Environmental Engineering

Bruce Ceniceros
California Energy Commission

Yvonne Chow
California Energy Commission

Rafia Dowar
California Energy Commission

Bill Eisele
South Carolina Electric & Gas

Rob Gray
Washington State Energy Office

Ken Henderson
HDR Engineering, Inc.

Lawrence Jentgen
EMA

Krista Kotur
Union Electric

James N. Poole
Electric Power Research Institute

David Reardon
HDR Engineering, Inc.

Special acknowledgment to Franklin L. Burton, Burton Environmental Engineering, for technical oversight.

Thanks also to those who previously contributed their time and expertise to this Guidebook for Quality Energy Efficiency Retrofits for Water Systems:

Stefan Abelin
ITT Flygt

Wendell Bakken
California Energy Commission

Dee Brookshire
San Juan Water District

Elizabeth Boynton
California Energy Commission

Jacques DeBra
City of Davis

Bob Bolno
City of Philadelphia Water Department

James Epp
Kansas City Board of Public Utilities

John P. Ford
Calleguas Municipal Water District

Skip Fralick
San Diego Gas & Electric

Chuck Gaford
Memphis Gas, Light & Water

Gunnar Hovstadius
ITT Flygt

Elizabeth Kawczynski
AWWA Research Foundation

T. K. Keller
Vandenberg Village Community Services District

Keith Kimes
City of Watsonville

Phillip Lawler
Moulton Niguel Water District

Tom Olson
Southern California Edison

Larry Pakenas
New York State Energy Research & Dev. Authority

Charles W. Pike
Department of Water Resources

Brian Platt
New York State Energy Research & Dev. Authority

Wendell Porter
University of Florida

Bob Schoech
City of Davis

Rodney Smith
Madera Valley Water Company

Gayland Swain
City of Watsonville

Charles Truax
Memphis Gas, Light & Water

Fred Von Hofe
Memphis Gas, Light & Water

Gary Wainwright
Pacific Gas & Electric

Horton Wasserman
Malcolm Pirnie, Inc.

Mark Watson
New York State Energy Research & Dev. Authority

Bob Web
Southern California Edison

Paul Williams
Southern California Edison

Table of Contents

List of Tables

List of Figures

1

Introduction

This manual is intended to help the project manager avoid overlooking critical issues which could affect the quality of energy project installations.

This manual provides information that can help operations and engineering staff in wastewater treatment plants successfully implement common energy-efficiency improvements. The manual's scope is limited to project implementation issues. Accordingly, it is assumed that the facility has already completed an energy assessment (often referred to as an *audit*).

This manual is targeted to staff who are actively involved in implementing energy efficiency improvements. It shares the knowledge and experience of wastewater and energy professionals who are familiar with energy efficiency improvements at wastewater treatment plants.

Most wastewater agencies engage in an ongoing process to improve the quality of their treatment and their operational efficiency. In general, facilities can implement two types of changes to improve energy efficiency: retrofits (equipment changes or additions), or operational modifications. This manual deals primarily with retrofits, although some changes to operation and maintenance procedures are suggested to improve energy efficiency. The manual outlines procedures that can be used to conduct a systematic retrofit to help prevent many potential pitfalls.

There are many important steps on the road to successful energy conservation. Figure 1-1 illustrates the process, starting with identification of excessive energy use and proceeding through the project implementation. These steps are discussed further in Section 2.

How to Use This Manual

This manual was designed so that operations and engineering staff can quickly locate specific information about a project. It shows how to proceed once an energy assessment has identified retrofit projects. Section 2 addresses important issues that should be considered for most types of retrofit projects. Sections 3 through 11 focus on critical issues and considerations relevant to specific types of retrofit projects, with recommendations for each phase of the implementation process.

This manual can be used to:

- Verify that essential information was included in a previous energy study.
- Determine which projects to implement, and why.
- Systematically proceed through each phase of a project using checklists.
- Warn of potential pitfalls.

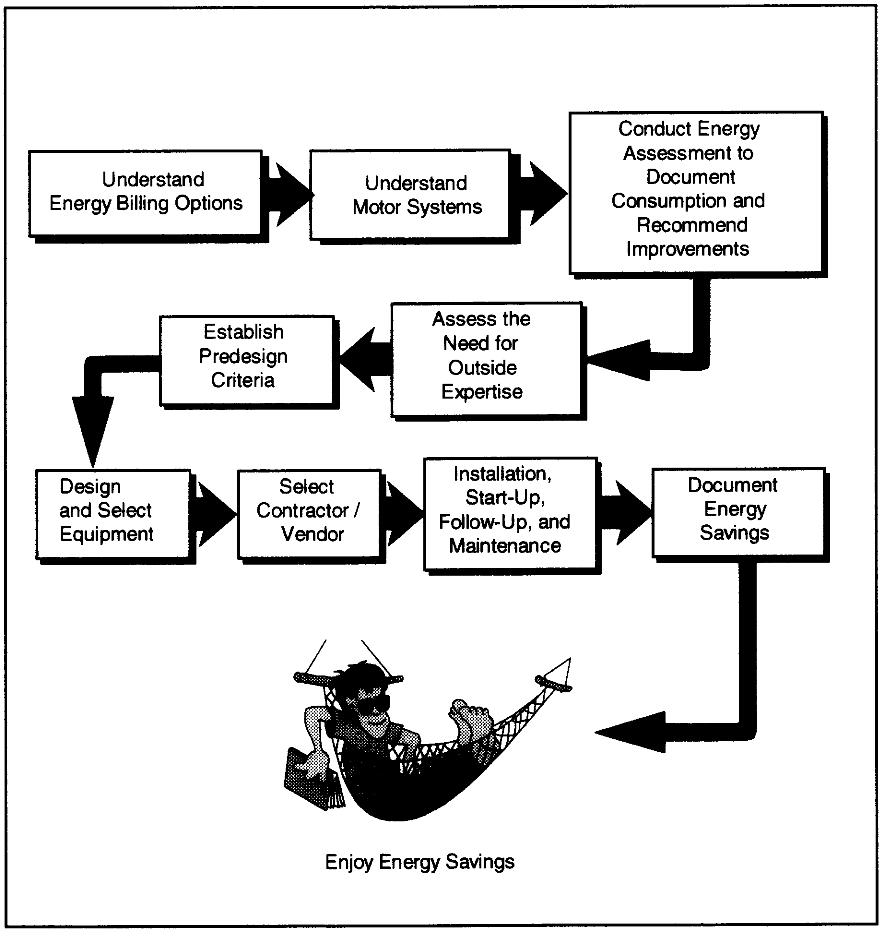

Figure 1-1. Retrofit Roadmap

The summary checklists at the end of each section can be included in reports, specifications, or other documents to help manage retrofit projects.

Additional Information

Additional information on energy management is available through the Electrical Power Research Institute's (EPRI) Community Environmental Center located in St. Louis, Missouri or at the California Energy Commission's *Energy-Water Connection.* Wastewater agencies can access the EPRI Center through their electric utility account manager. More information is available at the *Energy-Water Connection* Web site (http://www.energy.ca.gov/water).

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The Retrofit Process

Identifying Projects

Retrofits should always be preceded by a thorough energy assessment that provides an economic analysis of each proposed change or retrofit, an estimate of costs, and the anticipated energy savings. Most energy assessment reports constitute a planning level document. Of the recommended improvements cited in these reports, several can be implemented with little or no further design. This is typical of motor replacements and operational changes. However, larger projects that involve construction, new equipment, or input beyond the expertise of plant staff will require outside consultants for proper design.

Operational Changes and Retrofits

Energy costs can be reduced by implementing operational changes or retrofits. Operational changes can be made to a process or system without significant capital costs. Retrofits, however, often require significant expenditures for modifying or replacing existing equipment, or for installing new equipment. While this manual focuses primarily on retrofits, operational improvements for energy conservation should be made in conjunction with—or prior to—the proposed retrofits.

Most methods of reducing energy costs at wastewater treatment facilities can be grouped into one of the following general categories:

- *Shifting electrical loads to reduce peak demand.* Electrical load management is perhaps the most beneficial strategy for reducing operational costs for wastewater treatment facilities. Retrofits or operational changes that shift electrical loads and exploit time-metered electric utility rate schedules can be an inexpensive and attractive alternative for both the electric utility and wastewater agency. Facilities can realize savings in this area by shifting the operation of equipment to off-peak or partial-peak rate periods, or by avoiding simultaneous operation of equipment during on-peak rate periods. For example, dewatering can be rescheduled for off-peak and partial-peak rate periods, and the use of intermittently operated equipment can be adjusted for non-concurrent operation during on-peak rate periods. Variable-frequency drives (VFDs), time clocks, or programmable logic controllers (PLCs) can all effectively shift or minimize peak loads. Turning equipment off also reduces operational costs.
- *Process changes.* Process improvements can reduce the amount of energy required and still achieve specified levels of treatment. Operating the aeration process with dissolved oxygen control will reduce the energy used in the secondary treatment process. Maximizing the performance of the primary clarifiers will reduce loading on the activated sludge process which in turn reduces the energy needed for aeration.

- *Improving equipment efficiency.* Facilities can improve equipment efficiency by installing more efficient motors or impellers, replacing and maintaining pumps, or modifying other equipment.

Operations and engineering staff should also consider benefits other than energy efficiency when deciding on the most suitable retrofit process. Increased reliability and productivity, improved performance, better process control, and reduced operation and maintenance (O&M) costs—though sometimes difficult to quantify—accompany many energy efficiency retrofits.

Funding Energy Retrofit Projects

There are many options available for financing energy efficiency projects.

Funding is one of the major obstacles for energy retrofit projects. There are some exceptions: Some no-cost/low-cost process and operational changes can be made almost as soon as they are identified, and minor retrofits can be funded with existing O&M budgets or included in the following year's budget. However, funding large projects with higher capital costs is often problematic. Even the most cost-effective projects are vulnerable to delay or cancellation due to lack of funding. However, there are many options for financing energy efficiency projects, including the following:

- Conventional budgeting using the wastewater agency's capital improvement program (CIP).
- Inclusion of retrofit costs in the budget for major facility upgrades or expansion projects.
- Low-interest loans from state agencies.
- Grants or technical assistance from state energy offices and other agencies.
- Rebates, grants, or full-value loans from electric utility demand-side management (DSM) programs.
- Municipal pooled bond financing programs.
- Conventional loans from private banks (many banks credit the resulting energy cost savings towards collateral).
- Performance contracting—design/build projects that give a portion of energy cost savings to the contractor.
- Funds or loans from equipment manufacturers.
- Equipment leasing programs.

Although the process can be daunting, a number of financing options are available and should be investigated thoroughly. Financing programs sponsored by electric utilities are becoming increasingly popular, and utility account representatives can provide details of these programs. Also, energy service companies are becoming increasingly active as performance contractors.

Steps to a Successful Retrofit

A retrofit project requires more than simply choosing equipment from a manufacturer's catalog and installing it. As shown in Figure 1-1, the key steps to a retrofit are as follows:

1. Understand energy billing options.
2. Understand motor systems.
3. Conduct an energy assessment to document consumption and recommend improvements.
4. Assess the need for outside expertise.
5. Establish predesign criteria.
6. Design and select equipment.
7. Select contractors and vendors.
8. Perform installation, start-up, follow-up, and maintenance.
9. Document energy and cost savings.
10. Enjoy energy savings.

A discussion of each of these steps follows.

Understanding Energy Billing Options

The key to sound energy management is understanding how your facility is billed. The two main charges that appear on an electric bill are for energy and demand. *Energy* is the quantity of electricity used, measured in kilowatt hours (kWh). *Demand* is the power supplied by the electric utility, measured in kilowatts (kW). Because rate schedules and kWh/kW costs vary among electric utilities, retrofit projects must be tailored to maximize savings based on the available schedule. A variety of new billing options will become available as the electric utility industry is restructured, allowing wastewater facilities to buy their electricity from a provider of their choice. EPRI's *Energy Audit Manual for Water and Wastewater Facilities*[1] contains a brief discussion of billing rate schedules. Further information about electric bills can be found in EPRI's publication *Reduce Costs by Understanding Your Electric Bill,* which is included in Appendix A.

Understanding Motor Systems

When identifying and implementing energy projects, it is important to be aware that each piece of equipment is part of an interactive system. Making a change in one component may significantly affect the performance of another. For example, changing the discharge pressure of a pump will change its operating point on the pump curve. If the efficiency of the new point is significantly lower the impeller may need to be trimmed or replaced to recapture the difference.

When identifying and evaluating efficiency improvements, there may be several possible modifications that could improve the efficiency of a system. Thus, it is essential to look at the whole system and determine which measure or combination thereof will result in the biggest energy reduction for the investment. For example, an aeration system is comprised of blowers, diffusers, and a control system. Although installing fine bubble diffusers will reduce energy use by improving the oxygen transfer efficiency, even greater system efficiency could be obtained if a dissolved oxygen control package is also installed. With changes to the diffusers and control system, one must then evaluate the blower's ability to efficiently produce air at the new flow rates.

Conducting an Energy Assessment

The purpose of an energy assessment is to identify opportunities for improving plant efficiency and reducing operating costs, as well as to quantify the cost and savings of these options. A good energy assessment is a valuable decision-making tool for plant improvement options. It should be conducted by someone experienced in treatment plant design and with knowledge of electric utility rate schedules and energy management strategies. Although some larger agencies have personnel qualified in these areas, most do not. Facilities lacking this expertise should employ a qualified outside consultant.

The evaluator should determine how, where, and how much energy is being consumed in the plant. Each unit process should be analyzed for cost savings opportunities. The analysis should encompass a systems perspective, examining how various components interact and how potential changes may impact other processes in the plant. The simpler changes should be considered first—often changing electric rate schedules or operating methods can save as much energy as a complex and expensive equipment retrofit. The annual savings and cost for each option should be estimated based on the electric rate schedule, but should also include non-energy costs and savings that might result from changes in chemical use, maintenance requirements, materials, and labor. Ideally, a life-cycle cost comparison should be conducted that accounts for all likely fiscal impacts over the predicted life of the proposed modification.

Assessing the Need for Outside Expertise

Many wastewater facilities develop, design, and implement projects with their own engineering staff. The ultimate decision to hire engineering consultants for design or contractors for construction depends on staff expertise, time constraints, spending limits, and other factors. If consultants and contractors are used, it is important to check their references during the selection process.

Advantages of using outside consultants for evaluation and design are as follows:

- Experience with similar retrofit projects.
- Knowledge of potential pitfalls in the retrofit process.
- Knowledge of equipment and costs.
- Less reliance on performance claims by vendors.
- Potential for an accelerated project schedule.
- Less time required from in-house staff.

Disadvantages of using outside consultants for evaluation and design include the following:

- Potentially higher engineering costs.
- Not recognizing problems involving new equipment compatibility with existing equipment.
- Lack of awareness of operational impacts from the proposed retrofit.
- More coordination involved to facilitate communication between parties.

Advantages of using outside contractors for construction are as follows:

- Contractor may have the specialized experience and equipment necessary for implementing the project.
- Potential for faster installation.
- Less labor demands on O&M staff during installation.

Disadvantages of using outside contractors for construction are as follows:

- No guarantees of high-quality work (pre-qualification can help).
- Possible disruption of plant operation by construction workers.
- Potentially higher installation costs.

Predesign

For retrofits that require design, it is important to review the potential impact of each modification to determine strategies for resolving any complications. During the predesign stage, several key design elements must be established. Starting with the recommendation in the energy assessment report, staff must validate the preliminary size of equipment and/or processes, verify compatibility with existing equipment, determine the location of the planned retrofits, and identify all necessary appurtenances (i.e., electrical, HVAC, instrumentation). Structural, mechanical, electrical, process, and instrumentation issues must all be addressed for each retrofit. Failure to do so can result in a facility that is difficult to operate and unable to achieve the performance anticipated.

Design and Equipment Selection: Get What You Want in the Bidding Process

Many of the ideas, pitfalls, and equipment features described in this manual can serve as a starting point for the bidding process. Detailed drawings and specifications are also helpful in obtaining the proper equipment. However, a generic specification that does not name prequalified equipment must be exceptionally thorough to exclude undesirable equipment. Some designers prepare bid forms with the base bid centered around the prequalified manufacturers but allow additional prices from other manufacturers. Thus, the owner has the option of selecting from a prequalified list (of say, two to five manufacturers) or selecting an alternative lower-cost supplier that may also meet the specifications.

Contract documents should clearly state the methods used to measure performance, who performs the testing, and steps to be taken if performance is unsatisfactory. When appropriate, penalty clauses should be provided in the event that performance (such as energy use) does not meet specifications. Equipment performance can be verified by certified or witness testing at the factory; though this may not be necessary for some retrofit equipment. Field testing to verify performance or efficiency can be complex but may be the only means to accurately verify vendor performance claims.

Selecting Contractors and Vendors

Contractor Selection

Some wastewater districts make arrangements with reliable contractors to perform on-call services for relatively small projects. The contractor is selected and retained on a sole-source basis upon successful negotiation of cost and terms. Selection of one or more contractors to serve on-call is usually done after consideration of past working relationships and experience.

Larger projects are usually bid from detailed design drawings and specifications. Although contractors with the lowest bid are often awarded the project, it is essential to verify that they are qualified to perform the work. Some public agencies prequalify contractors by limiting bids to only those who have performed similar retrofit work and who can provide references.

Vendor Selection

Retrofit projects not requiring extensive design can be implemented by a vendor who supplies and installs the equipment. This approach is often used for energy efficient motors, VFDs, and some supervisory control and data acquisition (SCADA) systems. Because performance and reliability among vendors varies, it is critical to solicit bids from two or more vendors with proven experience who can provide references from similar projects. Allowing a single vendor or manufacturer to pre-engineer a system in exchange for sole-source selection can result in compatibility problems during future repairs or upgrades.

Installation, Start-Up, Follow-Up, and Maintenance

The retrofit process does not stop with design. Equipment installation, start-up, follow-up, and maintenance are important considerations that are discussed in detail in the following sections. Debugging or troubleshooting, more recently referred to as *commissioning*, has become more important with the increase of electrical technology. All contract documents should include language that provides commissioning (such as debugging, calibration, and balancing) for all new systems.

Documenting Energy and Cost Savings

After completing the project, it is important to evaluate the retrofit to determine if it meets the prior expectations of performance and energy savings. This documentation will justify retrofit expenditures. Accurate electric meter data records that include kW, kWh, kilovoltampere (kVA), load factor, and power factor—before and after the retrofit—are essential to compute savings.

Energy cost savings can be measured by:

- Changes in electric utility bills.
- Changes in unit energy consumption (i.e., kilowatthours per million gallons treated or pumped).
- Field measurements of energy consumption at each piece of equipment before and after the retrofit.

References

1. Electric Power Research Institute, 1994. *Energy Audit Manual for Water and Wastewater Facilities*, EPRI's Community Environmental Center, St. Louis, Missouri. (This document can be obtained through electric utility account managers.)

Additional Resources

- The California Energy Commission's *Energy-Water Connection* Web site (http://www.energy.ca.gov/water) includes a list of financing sources for energy projects.

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Variable-Frequency Drives

Variable-frequency drives are the most common electronic device used to control motor and equipment speed. VFDs eliminate the hardware used by mechanical or hydraulic adjustable-speed drives to control pump shaft speed. They work with motors of almost any size, in any location, from residential heat pumps to utility power plant fans, to pumps in wastewater treatment plants.[1]

Benefits of VFDs

In the last five years, VFD prices have dropped significantly, while performance and reliability have improved.

VFDs have numerous benefits. They are more easily operated and feature better power factors and lower audible noise than mechanical adjustable-speed drives. In the proper application, VFDs can achieve the following:

- *Reduce energy costs.* VFDs enable pumps, fans, or other equipment to track flow demands by decreasing motor speed, as opposed to burning up energy in flow control valves.
- *Increase capacity of standby generators.* VFDs require lower starting current, enabling standby generators to handle more load.
- *Improved control.* VFDs can be used to vary chemical feed rates and process equipment motor speed, allowing for more efficient process control.

How a VFD Controls Motor Speed

Conventional alternating current (ac) motors operate at constant speed when powered at a constant frequency (60 Hz). VFDs allow the ac frequency (and voltage) to be varied to a motor, resulting in varied speed. For example, a 60-Hz ac motor powered by a VFD with an output frequency of 30 Hz reduces motor speed by one half.

As shown in Figure 3-1, VFDs are mainly composed of the following three parts:

- *Rectifier.* Converts the fixed 60-Hz ac voltage input to direct current (dc).
- *Inverter.* Switches the rectified dc voltage to ac, producing variable ac frequency.
- *Regulator.* Controls the rectifier and inverter to produce the desired ac frequency and voltage.

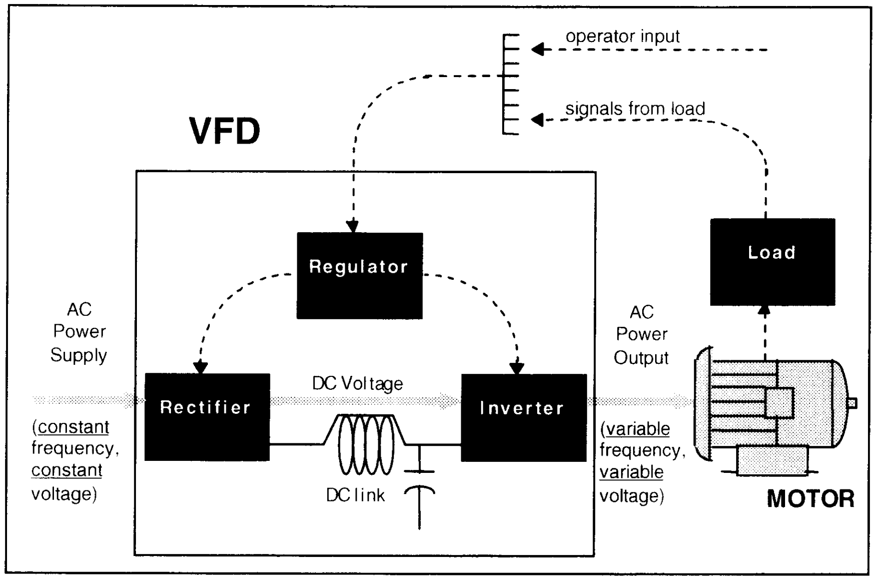

Figure 3-1. Configuration of an Electronic VFD

Types of VFDs

VFDs are differentiated by the type of inverters they use. Three types of inverters are on the market today: pulse-width modulated inverters (PWM), voltage-source inverters (VSI), and current-source inverters (CSI). Table 3-1 lists the advantages and disadvantages of each type. The following is a brief description of each.

- PWM drives. These are the most widely used drives on the market. These inverters accomplish both frequency and voltage control at the output section of the drive. These drives are common for applications under 100 hp but are available from 1 to 1,000 hp. Being a relatively new technology, the majority of installations are in the low-voltage range (120 to 600 V). However, they are currently expanding to include medium-voltage units.
- VSI drives. VSI inverters control the voltage and frequency to the motor to produce variable speed operation. These drives are similar to the PWM drives, except they use silicon control rectifiers (SCRs) for switching and only the frequency is controlled at the output of the inverter. Voltage is controlled at the input to the inverter, which results in poor speed control. These drives can distribute the drive signal to many motors simultaneously and are normally used for medium-voltage applications of up to 200 hp.
- CSI drives. The CSI inverter controls the current output to the motor. The actual speed of the motor is sensed by other circuits. This is then compared to the reference speed and an error is used to generate a demand for more or less current to the motor. The output switching devices, usually SCRs, are switched at the desired frequency to "steer" the current to the motor. CSIs are normally used for medium voltage (4160 V) single applications of 200 hp and greater.

Table 3-1. Advantages and Disadvantages of Different VFD Types

Type	Advantages	Disadvantages
PWM	• Bypass available in event of drive failure. • Can handle high-inertia loads. • Installation is simple with just three power leads to the motor. • Drives can be tested without the motor connected. • More than one motor can be operated from the same inverter. • Good power factor throughout the full operating range. • Self-diagnostics aid in troubleshooting. • Capital cost is less than CSI and VSI drives.	• Requires high-power components to handle power conversion. • Requires skilled technicians for service. • Audible noise. • Harmonics (filters may be required). • May require inverter-duty monitor.
VSI	• Bypass available in event of drive failure. • Can handle high-inertia loads. • Installation is simple with just three power leads to the motor. • Drives can be tested without the motor connected. • More than one motor can be operated from the same inverter.	• High capital cost compared to PWM drives. • Requires high-power components to handle power conversion. • Produces low power factor at low speeds. • Requires skilled technicians for service. • Audible noise. • Harmonics (filters may be required). • May require inverter-duty monitor.
CSI	• Bypass available in event of drive failure. • Can handle high inertia loads. • Current control limits fault currents.	• High capital cost compared to PWM drives. • Requires tachometer feedback for speed regulation. • Produces low power factor at low speeds. • May run to full speed if tach. signal is lost. • Inverter is matched to motor characteristics. • Inverter design requires motor connection to operate. • Typically the largest drive in overall physical size. • Produces more voltage notching than PWM drives. • All power must go through conversion.

PROJECT SUCCESS STORY

Carmel Area Wastewater District

Description of Facility: The Carmel Area Wastewater District (CAWD) operates a 4 mgd tertiary treatment plant in Monterey County, California. All effluent is reclaimed for use on area golf courses.

Project Description: CAWD has two return activated sludge (RAS) pumps, which are throttled into a common discharge line. Taking waste activated sludge (WAS) from this line required further throttling on the RAS line to increase pressure. The WAS line was then throttled to control the WAS flow rate. Two VFDs were installed and both RAS throttling valves were opened. The hydraulics allow the WAS throttling valve to control the WAS flow rate without further throttling of the RAS lines. The cost for installation and programming modification was approximately $63,000.

Results: An annual energy savings of approximately $18,000 has been estimated for the installation. The new VFDs have simplified control of the RAS pumping station and improved process flexibility.

Project Challenges: Due to limited space in the Motor Control Center (MCC) room it was crucial to verify that equipment dimensions matched the available cabinet space.

Available Features

Several add-on hardware features are available to customize VFD installations, including panel-mounted interfaces, network communication cards, and relay outputs. Programmable options also provide flexibility. The units available today have programmable user interfaces that allow the owner to set a number of operational parameters.

Which Motors Work with VFDs?

VFDs can work successfully on both induction and wound-rotor motors and are commonly installed on existing motors that are in good condition. However, under some circumstances, standard motors can be damaged by a VFD. For example, increased heating from harmonics can damage winding insulation. Voltage spikes can cause similar damage where long lead lengths (approaching or exceeding 100 feet) between the motor and VFD exist and no line filter is used. To avoid damaging existing motors, their suitability for use with a VFD must be checked prior to installation. Other situations warranting caution are described in the Project Implementation section of this chapter.

Motor cooling is also a critical factor. Power requirements of positive displacement pumps or blowers are directly proportional to speed. In these applications, as well as others, motors can overheat at speeds less than 50 percent of full nominal speed. Cooling is usually less of a problem in centrifugal pump and blower applications, where the load drops off more quickly with reductions in speed.

Motors are now available with inverter duty ratings. These motors are essentially high efficiency models with higher insulation ratings and under-rated to protect against harmonic current heating. Models with inverter duty ratings, and energy efficient models, perform better with VFDs than do standard motors.

Which Equipment Should Get the VFD?

It is not necessary to place a VFD on every piece of equipment to obtain the desired control. The energy assessment report should indicate which equipment could best use a VFD. The ideal equipment size will depend on the strategy used when the VFD is in operation. Before selecting a VFD, evaluate the changes it will have on operations in terms of the whole system, and compare the economics of a VFD against less costly alternatives. For example, pumping stations with multiple pumps can be staged to follow flow requirements and sequenced to optimize the overall efficiency of the pumping plant. Other applications may benefit from improved control with a VFD but achieve little or no energy savings, such as systems with high static head. This is because at full flow, most of the work done by the pump is required to overcome the static head. As the speed is lowered by a VFD, it quickly reaches the point where all of the work of the pump is required just to hold up the water column, moving little or no water.

Impacts of VFDs

VFD use can have certain side effects, all of which can be controlled with proper planning and design. The following is a discussion of some commonly encountered problems.

Harmonic Distortion

VFDs produce harmonic components that can contribute to high harmonic currents in the power supply. This may result in the need for electrical equipment, such as conventional power transformers or motors, to be derated (the effective capacity is reduced). Otherwise, a transformer or circuit breaker that has adequate capacity to handle a 60-Hz load could overload from high harmonic currents caused by the addition of a VFD. Therefore, transformers must be evaluated before VFDs are added.

Selecting a method to control harmonics is part art and part science. Although small VFDs may not produce significant harmonic currents, larger units can create substantial problems if steps are not taken to mitigate harmonics. For design purposes, these problems must be addressed. The type and magnitude of the problem can be characterized through a harmonic analysis.

There are several ways to solve harmonic problems. VFD isolation transformers effectively reduce harmonic currents but are usually the most expensive method. These transformers lower the amplitude of the fifth-, seventh-, and eleventh-order harmonics, which cause the most problems. Input reactors cost less than isolation transformers and can be just as effective. Harmonic filters reduce harmonic distortion levels by providing a low-impedance path for the harmonic currents. Many VFDs are now available with built-in harmonic filters. "Harmonic-free" PWM VFDs also control harmonics. They are fairly new to the market and require a careful comparison of cost and capabilities.

Unfortunately, there is no clear way to determine how to control harmonics. Larger installations require case-by-case evaluation by an experienced designer familiar with VFDs. For smaller applications, plant staff can experiment through trial and error.

Audible Noise

It is important to specify the acceptable limits of audible noise—in decibels—from the VFD controlled motor. PWM drives supply a relatively clean voltage to the inverters. This will also reduce the harmonic heating in the motor, but it can create an irritating high pitched noise due to the higher modulation frequency (on the order of several kilohertz). Generally, an output choke will reduce the higher-frequency harmonics in the motor that produce the audible noise.[3]

Capacitors

Facilities that have capacitors installed for power factor correction may experience problems when adding VFDs. Capacitors for power factor correction should not be applied to VFD-driven motors and are normally not needed. PWM drives have high power factors, thus eliminating the need for correction.

Equipment Conflicts

A VFD installed near a Doppler flow meter will cause problems with the flow meter. Similarly, VFDs can cause problems with other electronic equipment. VFD manufacturers can provide further information on compatibility problems with their units and existing equipment.

Project Implementation

Considerations relative to project implementation are as follows:

- Predesign criteria.
- Design and equipment selection.
- Installation necessities.
- Start-up, maintenance, and follow-up essentials.

Following are brief discussions of each. The checklist at the end of this section can facilitate project planning.

Predesign

- *Verify assumptions, benefits, and impacts.* Verify that the assumptions used for calculating the project economics were reasonable. Are estimates of run time (full-speed and variable-speed) and motor loading typical of normal operating conditions? Were the correct electric rates and demand charges used? Was a reliable method of cost estimating used? Note that electric utility deregulation could change the cost of electrical energy.
- *Verify that the proposed project makes sense for the site and application.*
    - Did the analysis properly address power quality issues? The predesign engineering report should consider potential harmonics problems and whether they should be a concern for your site.
    - Is the capacity and configuration of the electrical system sufficient for handling the type of equipment proposed?
    - Is there room to mount the drive in the motor control center or should it be mounted close to the motor in question?
    - Is the instrumentation compatible with existing controls?
    - Will increased noise be a problem?
- *Check original motor/equipment sizing.* Occasionally, motors or equipment are oversized for their actual operating conditions. Before sizing the VFD, evaluate whether the motor or equipment is optimally sized, and replace if necessary.
- *Check the suitability of the motor for variable-speed operation.* Most motors are suitable for variable-speed operation, but there are exceptions. Check that the motor/equipment combination will work properly at variable speed.

Confirm with the manufacturer or vendor that the motor is compatible with the selected drive. For example, motor cooling or vibration problems are possible if the motor is coupled to a positive displacement pump where power requirements are directly proportional to speed. In centrifugal applications, load rapidly decreases with a reduction in speed, thereby reducing cooling problems.

- *Check existing pump suitability.* Not all energy assessments will evaluate VFDs on pumps other than the ones currently installed. Look out for misapplications. Not all pumps are good candidates for VFDs. Determine whether the existing pumps are sized for use with VFDs. Determine the effect of speed changes on pump efficiency. Check their ability to operate at the lowest desired point. Will the critical speed be encountered? Does static head make up a large proportion of the total head? Would a new pump of a different size be more suitable for the flows anticipated? Will two pumps driven with VFDs provide better control? The sources referenced at the end of the chapter offer further explanation of VFD efficiency and a discussion of issues that should be considered when evaluating the suitability of a VFD application.
- *Is a cooling system required?* Higher-power-rated VFDs may require an air or water cooling system. Cabinets installed outdoors may require cooling to protect circuits in warmer climates. Ensure that the cost of a cooling system and the energy it requires to operate is accounted for in the cost estimate, and that there is sufficient space for the additional equipment.

Design and Equipment Selection

- *Control system integration.* Carefully consider integrating VFD controls into existing systems. The control strategy for the VFD should be integrated with plant control systems or energy management systems to realize the full savings. Include costs for the modification of control programs.
- *Future Programmable Logic Controller (PLC) inputs/outputs.* When designing and specifying VFDs, consider any future PLC input/output controls that will be needed.
- *Bypass isolation.* In most VFD installations, it is advantageous to provide an electric bypass-isolation mode. Bypass-isolation contactors allow the pump to operate while the VFD is out of service. When bypassed by switches or contactors, VFDs must be isolated on both the "line" and "load" sides. Power applied to load side only can damage the VFD.
- *Multiple estimates.* Never rely on a single cost estimate for equipment and installation. Obtain at least three estimates or bids from manufacturers, making sure that all required components and design considerations are included in the estimates. Verify that you are comparing apples to apples with each bid.
- *Check references.* Require at least three references from bidders with similar projects.
- *Evaluate manufacturer's services.* Location of the vendor or manufacturer can affect the availability of parts and service. Determine the type of support anticipated based on past experience.

Installation Necessities

- *Determine the best location.* In new projects, it is common to mount the drive in the motor control center (MCC), while in retrofit projects, it is common to mount the drive near the motor being controlled. Installing VFDs near the motor can expose the unit to flooding. If flooding has occurred in the past, it is best to mount the unit elsewhere. Occasionally VFDs are installed outdoors. These units should be protected from rain, moisture, chemicals, and excessive heat or cold conditions. Air conditioning and heating are commonly incorporated into outdoor VFD cabinets. This equipment must be accounted for in the project cost estimate.

- *Determine enclosure requirements.* Depending on the space required and length of feeder conductors, MCC mounting can be more costly. However, MCC mounting is preferred because VFDs normally come in NEMA 1 enclosures, which are not rated for wet, washdown, or corrosive areas. NEMA 3R & NEMA 4X can be specified.

Start-Up, Maintenance, and Follow-Up Essentials

The contract documents should require the manufacturers' representatives perform:

- *Services immediately upon VFD installation and before start-up.*
  - Supervise final adjustments, calibration, and installation check.
  - Simulate input signals to operate equipment.
  - Debug/troubleshoot programmable logic.
  - Complete start-up to full operational status.
- *Start-up and demonstration services.*
  - Supervise start-up of all units, with complete recheck of final adjustments, calibration, and commissioning. Perform all work in the presence of the wastewater facility's designated representative(s).
  - Check motor electrical requirements and supervise balancing of electrical loads. Perform full operation through standby mode of pumps or equipment. Demonstrate full capability of diagnostic test package.
  - Verify that the motor rotates in the correct direction.
  - Perform full troubleshooting of controller under simulated failure.
  - Upon satisfactory completion of startup and demonstration, submit reports that verify installation and check certification.
- *Training.* After start-up, instruct the wastewater facility's personnel at the job site regarding proper operation and maintenance, including programming troubleshooting, repair and replacement, parts inventory, and maintenance record keeping.
- *Maintenance.* Establish and maintain a schedule to calibrate all instruments that provide signals to control VFDs.

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Variable-Frequency Drive Retrofit Checklist

Predesign

- ❑ Verify that all assumptions used in economic analysis, such as motor loading and operating schedule, are reasonable.
- ❑ Evaluate power quality issues.
- ❑ Evaluate power system capacity.
- ❑ Verify sufficient space for VFD control unit.
- ❑ Consider the effects on other pieces of equipment and processes.
- ❑ Evaluate programmable logic controller compatibility with existing control systems.
- ❑ Establish acceptable noise level.
- ❑ Evaluate existing pump for use with VFD.
- ❑ Evaluate how pump efficiency will vary along the system curve as the speed is changed.
- ❑ Determine critical speed.
- ❑ Evaluate suitability of existing motor for variable speed operation.
- ❑ Determine how many VFDs are required.
- ❑ Determine if heating/cooling system is required.

Design and Equipment Selection

- ❑ Verify that controls are appropriately integrated into the automation system.
- ❑ Perform harmonic analysis for susceptible power systems.
- ❑ Include isolation transformer, input reactors, or harmonic filters, if required.
- ❑ Provide power system ground near motor terminals.
- ❑ Provide a bypass starter isolating VFD on both line and load sides.
- ❑ Compare cost estimates from three or more manufacturers.
- ❑ Evaluate manufacturer's support and service.

Installation

- ❑ Mount VFD in the most appropriate location.
- ❑ Units mounted outdoors are adequately protected from rain, moisture, and excessive heat or cold.
- ❑ Test interface with plant SCADA.
- ❑ Test for conflicts with existing instruments.

Start-Up

- ❑ Supervise final adjustments, calibration, and installation check.
- ❑ Simulate input signals to operate equipment.
- ❑ Debug/troubleshoot programmable logic controller.
- ❑ Complete start-up to full operational status.
- ❑ Check motor electrical requirements and supervise balancing of electrical loads.
- ❑ Verify that motor rotates in the correct direction.
- ❑ Check operation at various speeds.
- ❑ Perform full troubleshooting of controller under simulated failure.
- ❑ Submit reports that verify installation.

Training

- ❑ Require Manufacturer's representative to instruct owner's personnel on proper operation and maintenance of drive.

Maintenance and Follow-Up

- ❑ Calibrate, on a regular basis, instruments used to control VFD operation.
- ❑ Monitor monthly electric utility billings and compute savings.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

❹

Energy-Efficient Motors

Electric motors are the largest users of electric power in the United States, consuming over half of all electricity and more than 60 percent of that used in the nation's industrial sector.[1] The electrical cost to operate a typical motor over its lifetime can be 10 to 30 times the original purchase price.[2] Increased motor efficiency will reduce operating costs and energy consumption.

Energy-efficient electric motors (also known as *premium-efficiency* or *high-efficiency* motors) offer improved performance and substantial energy savings compared to standard motors. There are many differences between standard and energy-efficient motors. Energy-efficient motors use improved materials, such as lower-loss steel and thinner stator laminations. More active material is also used, including longer steel cores with higher copper and aluminum content. These motors generally have closer tolerances and more efficient bearings. Due to these differences, costs are 15 to 30 percent higher than standard motors.

Before the benefits of energy-efficient electric motors can be evaluated, efficiency must be defined. For an electric motor, efficiency is the ratio of mechanical power delivered (output) to the electrical power supplied (input).

$$\text{Efficiency} = \frac{\text{Mechanical Power Output} \times 100\%}{\text{Electrical Power Input}}$$

Therefore, a motor with an 85 percent efficiency rating converts 85 percent of electrical energy into mechanical energy. The remaining 15 percent of the electrical energy is dissipated as heat, as evidenced by increased motor operating temperatures.

Standards Define "Energy-Efficient"

Prior to 1989, there was no energy-efficient motor standard. Manufacturers were simply free to apply the term energy-efficient to the efficiency level of virtually any motor. In 1989, the National Electrical Manufacturers Association (NEMA) published their MG1 standards that included values of nominal and minimum motor efficiencies that manufacturers had to meet for motors marketed as energy-efficient. Even though those values were significantly higher than industry averages for standard motors, they were lower than those generally available with high-efficiency motors then on the market. In 1993, NEMA MG1 was modified with increased coverage of motor classes.

The Energy Policy Act of 1992 (EPACT) requires that most general-purpose motors sold in the United States after October 1997 must meet NEMA's *energy-efficient* definition. Table 4-1 shows the target minimum efficiencies for the motor classes covered by EPACT. Motors which exceed these levels, however, are readily available. The Consortium for Energy Efficiency has developed a standard for *premium-efficiency* motors that exceeds EPACT efficiencies by 1–4%, and can be used as a specification when purchasing new motors.[3]

Table 4-1. Minimum Full-Load Nominal Efficiency Levels Under EPACT[2]

hp	Open Motors			Enclosed Motors		
	3600 rpm	1800 rpm	1200 rpm	3600 rpm	1800 rpm	1200 rpm
1	----	82.5	80.0	72.5	82.5	80.0
1.5	82.5	84.0	84.0	82.5	84.0	85.5
2	84.0	84.0	85.5	84.0	84.0	86.5
3	84.0	86.5	86.5	85.5	87.5	87.5
5	85.5	87.5	87.5	87.5	87.5	87.5
7.5	87.5	88.5	88.5	88.5	89.5	89.5
10	88.5	89.5	90.2	89.5	89.5	89.5
15	89.5	91.0	90.2	90.2	91.0	90.2
20	90.2	91.0	91.0	90.2	91.0	90.2
25	91.0	91.7	91.7	91.0	92.4	91.7
30	91.0	92.4	92.4	91.0	92.4	91.7
40	91.7	93.0	93.0	91.7	93.0	91.7
50	92.4	93.0	93.0	92.4	93.0	93.0
60	93.0	93.6	93.6	93.0	93.6	93.0
75	93.0	94.1	93.6	93.0	94.1	93.6
100	93.0	94.1	94.1	93.6	94.5	93.6
125	93.6	94.5	94.1	94.5	94.5	94.1
150	93.6	95.0	94.5	94.5	95.0	94.1
200	94.5	95.0	94.5	95.0	95.0	95.0

Benefits of Energy-Efficient Motors

- *Lower energy costs.* High-efficiency motors use energy more efficiently, and their superior design may allow them to provide a higher power factor.
- *Durability.* Because of the high-quality design and materials, energy-efficient motors generally last longer, require less maintenance, and are more reliable—resulting in less equipment downtime. Consequently, energy-efficient motors often carry a warranty two to three times longer than those for a standard motor.
- *Improved tolerance to over-voltage.* Many energy-efficient models are more resistant to over-voltage conditions.

- *Interchangeability.* Design improvements are internal to the motor and do not affect the frame size or mounting dimensions.
- *Lower noise.* High-efficiency motors run quieter than standard motors.

Project Implementation

There are several key considerations relative to project implementation. The checklist included at the end of this section can facilitate project planning.

Predesign

Replacement of electric motors normally does not require further design. The staff at most facilities is capable of making the change, while other facilities have electricians contracted for small projects.

- *Verify assumptions.* Confirm that the assumptions used for calculating the project economics were reasonable. Are estimates of run time and motor loading typical of normal operating conditions? Economics of replacing standard motors with energy-efficient motors are highly dependent on how much the motor is used. A sump pump motor may never repay a cost premium via energy savings, while the same motor on a process pump, operating continuously, could pay back its cost in just a few years. Were the correct electric rates and rate schedule used? Was a reliable method of cost estimating used?
- *Verify that critical issues were addressed.* Confirm that the proposed project makes sense for the site and application. Did the analysis address the system as a whole? The report should identify potential site-specific problems. Was the original motor properly sized? Should the high-efficiency motor be the same size as the original?
- *Adapting frame size.* This cost must be included in the total replacement cost. This typically applies only when changing motor size or brands.

Design and Equipment Selection

- *Evaluate the effect of increased operating speed.* On average, energy-efficient motors operate at 5 to 10 revolutions per minute faster at full-load than equivalently sized standard motors. This can result in increased energy consumption on centrifugal loads (e.g. fans and pumps) if the increase in work cannot be used. If it can be used, the speed difference will still reduce the expected energy savings for centrifugal loads such as pumps, where load varies as the cube of the flow rate. For example, a 40-rpm speed increase in a four-pole motor will increase flow by only 2.3 percent but boost energy consumption by 7 percent, more than offsetting energy savings expected from improved efficiency.

  Unless a speed increase is desirable, try to select an energy-efficient motor with close to the same full-load speed as the motor it is to replace. Such a motor is usually available. MotorMaster motor selection software, available from the U.S. Department of Energy, includes data on motor efficiency and full-load speed for most available models and can aid in the selection process.[4] If it is not possible to match speed, the speed of the driven load can sometimes be adjusted by changing pulley size.

- *Specify motor which meets expected torque requirements.* Energy-efficient motors meet the torque requirements specified in NEMA Design B, but do not exceed them by as much as many older motors. As a result, an older motor that operates successfully under torque requirements that substantially exceed Design B specifications should not automatically be replaced with an energy-efficient motor of the same specification. Select a new motor that meets the expected torque requirements.
- *Payback periods vary by motor load.* Nameplate efficiencies are based on a motor's full-load operation; efficiency changes at other loads. At about one-half load and below, efficiency decreases rapidly. In such cases, motor manufacturers can generally provide reduced-load efficiency data. Figure 4-1 offers calculations to help determine simple payback when switching to an energy-efficient motor.

1. Assume that the load does not change.
2. Calculate reduction in electrical load:

$$kW_R = (0.746) \times (hp) \times \left(\frac{1}{Eff_S} - \frac{1}{Eff_e} \right)$$

3. Calculate annual savings*:

Annual savings = $(kW_R \times \text{runtime} \times kWh_C) + (kW_R \times kW_C \times 12 \text{ months})$

4. Motor cost:
   a. If existing motor is due for repair: $C_I = C_e - C_r$
   b. If replacing a working motor: $C_I = C_e$
5. Simple payback: $\text{Years} = \dfrac{C_I}{\textit{Annual Savings}}$

Term Definitions:

kW_R = reduction in electrical load in kW

hp = operating horsepower of motor

Eff_s = efficiency of standard motors

Eff_e = efficiency of energy-efficient motor

kWh_C = electrical rate in $/kWh

kW_C = monthly demand charge in $/peak kW

C_I = incremental motor cost

C_e = cost of energy-efficient motor

C_r = repair/rewind cost of existing motor

runtime = annual hours of operation

* *This calculation is not valid for centrifugal loads if the energy-efficient motor will run faster than the original motor.*

Figure 4-1. Simple Payback Determination for Conversion from Standard Motor to Energy-Efficient Motor

- *Match Motor Size to Load.* Underloaded motors have low efficiency and poor power factor. They are often found in older facilities when operating conditions have changed or in newer facilities that have been overdesigned to meet future conditions. Where motor efficiency drops rapidly below fifty percent of rated load, power factor decreases gradually from full load. Since larger motors typically have higher efficiencies than small motors there is seldom any energy reduction achieved by changing to a smaller motor. However, in areas where the electric utility charges for poor power factor, a cost savings could be obtained with a smaller motor. Before installing a smaller motor it is important to verify the full operating range to insure the motor can adequately drive the load.
- *Shopping for new motors.* Besides using the simple payback formula, manufacturers have simplified comparison shopping with guides or tables from which cost-comparison data can be estimated. Other manufacturers have computer programs that provide this information after entering data about the intended application.

Start-Up, Maintenance, and Follow-Up Essentials

The start-up and maintenance of electric motors is rather simple compared to larger retrofit projects. The owner's manual supplied by the motor manufacturer is the best guide for individual requirements. At a minimum the following should be done:

- Verify that motor rotates in the correct direction.
- Test motor with VFD (where applicable).
- Test motor with PLC input.
- Establish a maintenance schedule per manufacturers' specifications.
- Monitor performance regularly.

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Energy-Efficient Motor Retrofit Checklist

Predesign

- ❑ Verify that assumptions used in the economic analysis, such as motor run times and rate schedules, are correct.
- ❑ Verify that a high-efficiency motor is appropriate for a particular application.
- ❑ Verify that the motor will be compatible with the existing frame.

Design and Equipment Selection

- ❑ Evaluate impacts of increased motor speed.
- ❑ Verify motor compatibility with VFD (if used). Determine if there are critical mechanical frequencies to consider.
- ❑ Specify proper motor size and torque characteristics.
- ❑ Match motor size to load.
- ❑ Specify motor protection requirements such as thermal overloads, moisture detection, and resistance temperature devices.

Start-Up

- ❑ Verify that motor rotates in the correct direction.
- ❑ Perform troubleshooting services (by contractor).
- ❑ Test operation with VFD.
- ❑ Test operation under programmable logic control.

Follow-Up and Maintenance

- ❑ Monitor monthly electrical utility billings and compute savings.
- ❑ Establish and follow a motor maintenance program.
- ❑ Monitor motors regularly for decrease in performance.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

5

Supervisory Control and Data Acquisition (SCADA) Systems

Advances in computer hardware, communication networks, and software continue to enhance the control and management of wastewater treatment plants. In addition to improved control within the treatment plant, operators can make informed decisions related to energy savings based on plant information collected and processed by the SCADA system.

Many older plants still operate under their original control systems and could benefit from an upgrade. When assessing the feasibility of upgrading controls and data acquisition capabilities, facilities should evaluate the cost benefits associated with potential energy savings, as well as the other benefits.

Benefits of SCADA Systems

SCADA systems save energy, labor, and maintenance costs; improve data collection and storage; and afford better process control.

SCADA systems automatically monitor and control wastewater treatment plants. There are a variety of benefits:

- *Energy cost savings.* A SCADA system provides a central location for monitoring and controlling remote energy consuming devices. Decisions regarding when to run specific equipment are made with the aid of computer logic. The ability to schedule operations, automatically start and stop devices—coupled with software-driven decision-making—can result in the most efficient operation of blowers, aerators, pumps, valves, chemical feed systems, and other equipment. SCADA systems can effectively achieve cost savings by facilitating pumping during off-peak hours when rates are usually lower. This type of control can be achieved on a real-time basis, which will be especially important in the deregulated electric market, in which electric rates are expected to vary hourly or even continuously.
- *Reduced operating and maintenance costs.* SCADA systems help optimize staff time and other resources by providing continuous and precise control of process variables. This automated control frees staff hours previously spent making rounds to record data and adjust equipment. Operators do not need to be on-site during all hours of operation if the SCADA system has remote access capabilities. The central computer generates maintenance reports, sends alarms to operators, and prints work orders when equipment needs scheduled or emergency maintenance.

PROJECT SUCCESS STORY

Upper Gwynedd Towamencin Municipal Authority

Description of Facilities: The Upper Gwynedd Towamencin Municipal Authority (UGTMA) operates a 4.5 mgd wastewater treatment plant in eastern Pennsylvania.

Project Description: UGTMA retrofitted their SCADA system to include an energy management feature that monitors demand on a real-time basis. Simultaneously, they established a target demand for each month. An alarm system was included in the package that notifies operators if the targeted demand is being approached. Operators can then implement load shedding in the plant to quickly reduce demand and stay below the target.

Results: Over the course of several years they have systematically reduced their electric demand and demand charges. Their average monthly demand has dropped 23 percent, from 655 kW to 506 kW. This has resulted in an average monthly energy cost reduction of $4,965 or $59,580 annually!

Project Challenges: The project was relatively simple and the programming was done by the Authority staff. Developing a load shedding scheme that can be implemented at any time of the day requires operators awareness of current conditions and knowledge of the treatment process and permit requirements for effluent discharge.

- *More timely information.* Results are readily available because information is monitored on a continuous basis. Automatic data recording and report generation eliminate the need to manually record and report process parameters. DO levels can be monitored on a real-time basis for optimizing aeration systems. SCADA systems develop trends of critical process parameters quickly and easily, to help with data analysis.
- *More accurate process control.* Centralizing control and including programmable control logic enhances field equipment control. For example, operating blowers to maintain set DO levels reduces energy costs. More accurate control of chemical feed processes, such as those used for chlorination, can lower chemical usage. The ability to meet discharge standards is improved with better control at the treatment plant.

SCADA Components and Operation

A typical SCADA system consists of a Supervisory Control Station or Master Station, remote terminal units (RTUs), communications devices, interconnecting conductors required for the input/output (I/O) to the RTUs, primary elements, and transmitters used to monitor and control process conditions, and software for automatic monitoring and control of the system. RTUs can include programmable logic controllers (PLCs).

The Master Station usually consists of one or more computers with operator interface capabilities, including a keyboard, color monitor, report printer, event and alarm printer, hard disk drive, network interface, and uninterruptible power supply (UPS). A tape or optical disk is often included for archiving data. Projection video and large screen monitors are included in some systems. The RTUs are typically connected to a Master Station by radio, fiber optics, or a leased telephone line. Most RTUs have their own microprocessor and control the process by monitoring field inputs and performing various control functions (starting pumps, opening valves, etc.) by transmitting electronic signals as programmed.

Typical RTU I/O points consist of analog (proportional) and discrete (on/off or start/stop) signals. Analog signals are usually 4–20 mA or 24 Vdc. Digital signals can be of various voltage levels from 12 Vdc to 120 Vac. The I/O point information is transmitted to the Master Station and converted to graphical displays. From here the operator can view process conditions, such as wetwell level, flow, water pressures, and equipment operating conditions. This information can be archived on tape or disk for future reference. Operations such as starting or stopping pumps and opening or closing valves, may also be manually controlled from the Master Station. Various graphical displays can be created by the user at the Master Station.

Figure 5-1 is a simplified SCADA system schematic. RTUs are shown in typical applications used to control and monitor critical treatment components. The Master Station, which allows for operator interface to the control system, is shown at the treatment plant. In some instances, this may be part of an integrated system located at some other centralized location that is used to monitor and control additional municipal facilities.

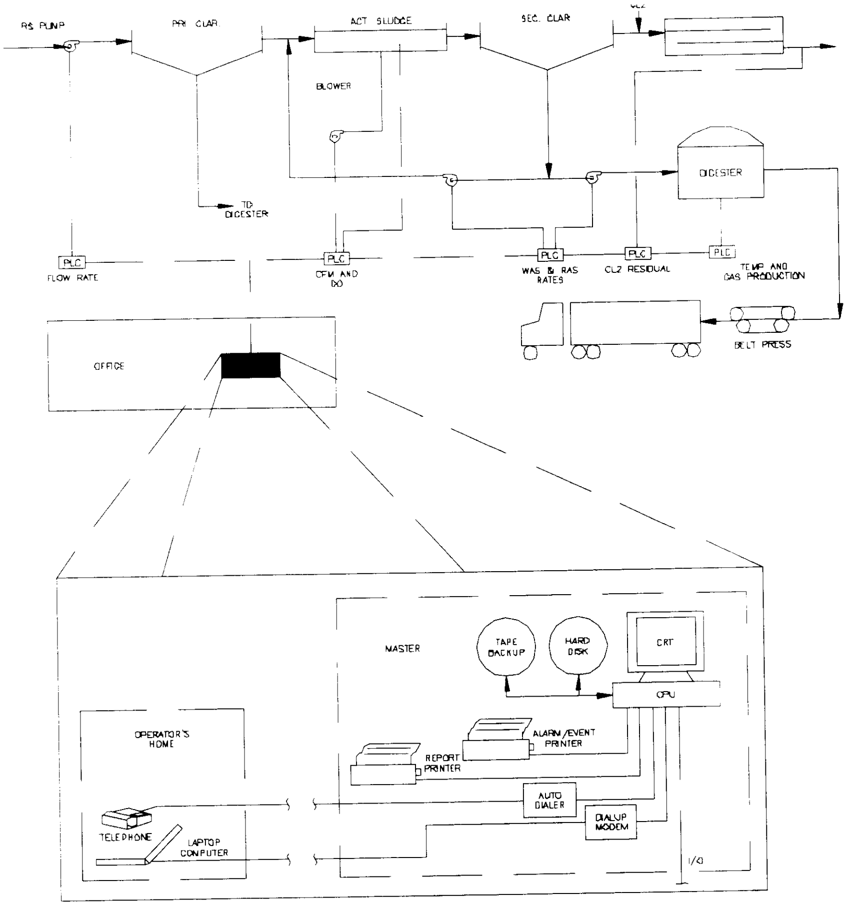

Figure 5-1. Simplified SCADA System Schematic

Energy Management Through SCADA

Energy management can be integrated into a SCADA system, which is perhaps the most cost-effective mode of operation at a treatment plant. This is accomplished by integrating real-time energy data from the plant's electric service with billing schedules and operational setpoints. Combining this information allows the plant to sequence equipment to reduce on-peak operations and minimize energy costs. The most important principle to emphasize is the advantage of monitoring electrical demand on a real-time basis. Because the demand charge often constitutes a significant portion of the monthly bill, monitoring and reducing unnecessary peaks can bring about significant savings without sacrificing service.

SCADA systems with automatic and remote control capabilities can facilitate load management. However, some electrical demand management strategies can be effectively carried out with simpler controls or through manual control. A target demand should be set based on an engineering evaluation. If not already present, an electrical demand meter should be installed with a system to warn operators when the target demand is being exceeded. The need to cycle-off equipment manually or through a SCADA system will depend upon several factors, including the complexity of the system, the skill of the operators, and budget constraints for implementing improved control schemes. An automated energy management system must also address the treatment objectives, which introduces additional constraints. The following software features should be considered for a SCADA based energy management system:

- Real-time monitoring, load reduction, or demand load-shedding (kW), to take better advantage of time-of-use rate structures.
- Monitoring of real-time electrical energy prices from a variety of suppliers and selecting the lowest-cost power available. This capability will be advantageous as electricity markets are deregulated.
- Alarms that sound when demand target is exceeded or when pump or other equipment's efficiency changes from target condition.
- Automatic filling of an equalization basin when high flow rates occur during on-peak rate periods.
- Prioritized selection of the most energy-efficient (kWh/Mgal) pumps.
- RAS and WAS VFD adjustment based on influent flow rate.
- Blower adjustment based on dissolved oxygen setpoint.
- Locking out certain equipment during on-peak periods.

The energy assessment report (refer to pages 1-1 and 2-1) should establish the level of control to be achieved. Goals of the SCADA energy management system (EMS) should be discussed in a workshop format. Participants could include representatives from the electrical utility, along with individuals or consultants with strong technical backgrounds in SCADA/EMS systems and DSM. Participants from the agency should include general managers, supervisors of operations, planning engineers, and SCADA system managers.

Types of SCADA Systems

Energy management software is an extremely important, but often neglected, consideration in SCADA system design.

SCADA system energy optimization must be addressed on a case-by-case basis. Considering that microprocessor-based monitoring and controls in the wastewater industry are relatively recent, the control center of the future should bring about even greater efficiency gains.

Three levels of control have been suggested as a framework for future SCADA system development: manual setpoint control; automatic setpoint control; and setpoint control with provisions for maintaining treatment objectives.

The level of control of each SCADA system should be determined based on the potential savings available through real-time monitoring and control. Basic SCADA systems are designed to monitor the treatment process and provide easy access to process data. This information helps operators report and troubleshoot problems but does not help prevent equipment failures or reduce the work load.

Adding alarms to warn operators of impending equipment or process malfunctions enhances the system. Alarm function can add a layer of protection to the equipment and the treatment process by allowing operators to respond to events before they become costly. Combining process control with real-time monitoring and alarming enables a SCADA system to reduce the operator's work load. Based on monitored process information like flow rates and DO levels, a SCADA system's logic can be programmed to start, slow down, or stop equipment in response to a change in the process parameters. These automatic adjustments enable the treatment process to operate at optimum conditions continuously where, in the past, such changes were made periodically through the day by the operators.

The following sections discuss considerations and critical issues for the establishment of predesign criteria, design and equipment/software selection, installation, start-up, and follow-up/maintenance procedures.

Project Implementation

Predesign

- *Include electric utility's rate schedule in preliminary analysis.* Changes to operations that will be incorporated into control schemes should take advantage of the electric utility's rate structures. A SCADA upgrade may provide new control options, so alternative rate structures should be considered. Demand versus energy charges should be distinguished and fully understood before developing control strategies for major equipment items.

- *Interruptible rate schedules offer lower electric rates* in exchange for electric service that can be curtailed or eliminated when required by the electric utility. By working closely with the electric utility, some wastewater agencies have been able to recognize significant rate reductions for participating in an interruptible rate schedule.

- *Define the requirements of the SCADA system.* Prior to design, define what equipment, valves, pumps, and power monitoring abilities should be incorporated into the SCADA system. The extent of the automation retrofit should be based on the ability of the existing equipment to accommodate the proposed control schemes. The SCADA system design should be flexible and consider electric rates, electric suppliers, and growth.

- *Consider using standby power to trim peak demands.* One option for running standby power is to provide contacts on an automatic transfer switch, which are tied to the SCADA system real-time demand monitoring and alarm system. If the threshold demand is exceeded and operators cannot shut down non-critical equipment, standby power can be started automatically.

- *Develop preliminary control schemes.* Based on the results of the energy assessment, incorporate the energy-efficiency-related control schemes into the SCADA system design. Control descriptions should be developed to describe the energy-related functions of the proposed SCADA system. Convey these functions to the SCADA system designer in addition to the normal monitoring and control functions. A modern SCADA system can be used to communicate with the electric utility and assess the effects of temporarily disabling electric equipment after receiving a load-shedding call. Pre-programmed setpoints can be used to temporarily allow DO levels to increase, and/or bring standby power on-line automatically.

- *Determine the communications medium.* Planning ahead can help ensure that the system is compatible with existing instrumentation and implemented in a timely manner. There are several communications systems from which to choose. Metallic or fiber-optic cable can facilitate local communications. Outside SCADA communications can be facilitated by leased data circuits, radio, or metallic or fiber-optic cable. Radio communications generally include VHF, UHF, or microwave frequencies. The advantages and disadvantages of each medium are presented in Table 5-1.

- *Determine hardware/software platforms.* Specify open architecture and nonproprietary software. Issues to consider include ease of expansion of alternative systems or if an outside consultant will be necessary.

Table 5-1. Advantages and Disadvantages of SCADA Communications System Types

Type	Advantages	Disadvantages
In plant: Hard wire	• Inexpensive	• Susceptible to noise and transients
In plant: Fiber optics	• More capacity • Less interference	• Higher cost than hard wire
Outside: Hard wire	• Immune to electrical noise, high speed, very reliable	• High cost
Outside: Telephone	• Low initial cost • Maintained by telephone company • Wide range of rates available	• Potentially unavailable during storms or natural disasters • Recurring costs can be substantial
Outside: Radio	• Owner operated and maintained • Reliable • Low recurring costs	• High initial cost • May require repeater(s) in hilly terrain • Requires license • Frequencies may be difficult to obtain • Limited data rate

Design and Equipment/Software Selection

- *Include provisions for energy management system.* Consider incorporating features that will enhance the monitoring and control of energy-intensive devices. This analysis should be performed by qualified personnel familiar with wastewater treatment process parameters. The electric utility may be able to provide pulse initiators or direct-read digital meters that can be tied to electric meter contacts to monitor real-time electrical demand in kilowatts. Operators can set a target demand for each month and have alarms notify the staff if the target is exceeded. A prioritized order of load shifting can be established to keep the demand under target. Decisions about cycling equipment can be pre-programmed into the control logic or left to the operator's discretion.

- *Check compatibility with existing hardware and software.* It is important to select equipment that will interface easily with the existing system and allow for expansion. Communication between different platforms is difficult to debug and makes future projects tougher to install. In addition, many agencies have personnel knowledgeable in programming and instrumentation. It is important to involve plant personnel with the selection of hardware and software to insure they are familiar and comfortable with the equipment selected. The ability to upgrade software and hardware in the future must also be considered.

- *Involve operators and maintenance personnel in design and construction.* Involving operations and maintenance personnel in design and construction will help them develop an early understanding of the system and prepare them to troubleshoot and customize it to meet their needs. If maintenance personnel are familiar with the equipment, system repairs can be made without unnecessary delays and costs for outside services.

- *Develop contractor selection criteria.* The requirement for publicly owned agencies to accept the lowest bid can present problems when reviewing proposals from system integrators. A wastewater agency can overcome this problem by implementing procurement processes that include considerations other than the low bid for evaluating proposals, such as a negotiated purchase, credibility of the system integrator, and prior performance–as well as the quality of the proposed system.

- *Keep it simple.* User-friendly systems are especially important for small- and medium-sized facilities. Consider systems that can be modified by in-house staff rather than using a consultant or the original supplier. Ask the supplier or designer to demonstrate how to change screens, modify software, etc., to verify that the system is simple enough for in-house staff to change. The energy elements of the system should be readily modifiable to reflect changes in electrical billing schedules or billing rates.

- *Insist on local vendor support.* Out-of-state vendor support can be expensive and inconvenient.

- *Decide whether to use a system integrator and/or a third-party engineer to design the system.* A critical decision related to the installation of a SCADA system is whether to allow a system integrator to develop the system independently or to incorporate engineering services to define the control concepts, operating parameters, and equipment requirements. Allowing the system integrator to determine the best configuration of software and hardware components eliminates the intermediate steps and can, in some instances, reduce both design and construction costs.

  However, a third party-engineering firm can prepare contract plans and specifications, help identify process-specific requirements, and maintain competitive bidding for the construction services.

  The utility should continue to provide input during the design phase. Encourage input from operators and maintenance staff. Personnel familiar with the facilities and operating parameters should review preliminary design submittals.

- *Include adequate training budget.* When defining the system integrator's responsibilities, include ample operator training in the contractor's scope of work. Operational changes resulting from implementing a plant-wide or system-wide SCADA system can be overwhelming if operators are not fully educated about the process. The technology can be intimidating unless a level of familiarity is developed. For training, a classroom format is desirable, but other formats (such as hands-on) also work. The contractor should be required to provide complete documentation on system operation and maintenance. The amount of training required will vary depending upon the complexity of the system and the background of the operators. Some staff may require basic computer training prior to being trained on operation of the SCADA system. Staff skill requirements should be reviewed and appropriate training planned.

Installation

- *Maintain field representation during construction.* A plant owner's representative should be involved in the construction process to ensure that the design intent is being met. The system designer should work directly with this representative to review all control loops, using detailed factory tests prior to installation and start-up.
- *Perform system testing.* Prior to installation, a factory or field simulation test should be performed, preferably with technical and operations staff. System functionality, communications, logic and typical system facilities (simulated) can be tested to demonstrate how efficiently the SCADA system works. This also serves to provide initial operator training.

Start-Up

- *Verify instrument calibration.* For the system to operate as intended, it is essential that instruments have been correctly installed and calibrated. DO levels should be checked against laboratory readings. Both wetwell levels and valve positions should be checked against manual readings. Pump and blower discharge pressures and flows should be checked against the manufacturer's equipment curves to verify that anticipated conditions are being met. This includes verifying that every point from the computer terminal to the field device is correct.

Follow-Up and Maintenance

- *Monitor monthly billing to compute savings.* Finance personnel and plant operators should discuss monthly billings to determine energy cost savings. Energy bills should be coordinated with flow information by calculating a monthly value for *specific energy*, the energy required to pump/treat a given volume of wastewater, measured in kWh/Mgal. Because flow can vary significantly from month to month, comparing specific energy is much more meaningful than simply tracking energy costs or kilowatt hours. Operators should be provided with a copy of the monthly billing statements and encouraged to identify areas for additional savings. A billing verification system should also be discussed with the electric utility to determine if/how the SCADA system can compute the electric bills.
- *Implement program for continued improvement.* Involve operators in monitoring and improving the system. Conditions change due to seasonal variations and new developments. A program should be developed to address maintenance issues as they arise.
- *Calibrate instruments regularly.* To maintain accuracy and control, it is important to keep field instruments calibrated.

References

1. Karassik, I.J., Krutzsch, W.C., Fraser, W.H. and Messina, J.P., 1986. *Pump Handbook*, McGraw Hill.

Additional Resources

- American Water Works Association Research Foundation, 1993. *Instrumentation and Computer Integration of Water Utility Operations.* (Order no. 90588).
- Walski, T. M., 1993. "Tips for Saving Energy in Pumping Operations." *Journal American Water Works Association* 85 (7).
- Chase, D. V. and Ormsbee, L. E. 1993. "Computer-Generated Pumping Schedules for Satisfying Operation Objectives." *Journal American Water Works Association* 85 (7).

SCADA System Retrofit Checklist

Predesign

- ❑ Do the proposed control schemes take full advantage of the electric utility's rate schedule?
- ❑ Will an interruptable electric rate schedule work?
- ❑ Define the limits of the SCADA system. What equipment, valves and pumps will be incorporated?
- ❑ Consider using standby power to trim peak demands.
- ❑ Determine whether the SCADA system architecture includes provisions for real-time demand monitoring and control of energy-intensive equipment.
- ❑ Can a knowledge-based control strategy be used to optimize operations based on historic demands?
- ❑ Determine the communications medium, and address licensing and reliability issues.

Design and Equipment/Software Selection

- ❑ Is energy management software included?
- ❑ Describe the energy-efficient functions of the SCADA system.
- ❑ Is hardware and software compatible with the existing system?
- ❑ Can hardware and software accommodate future upgrades?
- ❑ Involve operations and maintenance personnel in predesign, design, and construction.
- ❑ Develop contractor selection criteria prior to soliciting bids.
- ❑ Can the software be easily modified by wastewater agency staff?
- ❑ Is local support for the SCADA system available?
- ❑ Evaluate the pros and cons of using a third-party engineering consultant and/or a system integrator.
- ❑ Include adequate training budget for operators in the contractor's scope of work.

Installation

- ❑ Require the system integrator to perform detailed factory tests with involvement from the design engineer and operators.
- ❑ Provide plant owner's field representative during construction.

Startup

- ❑ Perform a point-to-point test for each I/O point.
- ❑ Calibrate instruments and debug logic.

Follow-Up and Maintenance

- ❑ Monitor monthly billing to compute actual savings in terms of benchmarks such as kWh/Mgal or dollars/Mgal.
- ❑ Implement a program for continued improvement.
- ❑ Calibrate instruments regularly.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

6 Pumping Station Modifications

Pumps are the most common piece of equipment in a wastewater treatment facility. As such, their efficiency can significantly affect the operational cost of a plant. Low pump efficiency can be due to overdesign or a result of worn parts and changes in operating conditions.

Ideally, the actual discharge and head produced by a pump will match the pump's best efficiency point (BEP). The BEP is the rated capacity of a pump, which occurs at the pump's maximum efficiency. When the operating head is higher than that anticipated in design the pump's discharge will be less than that of the BEP. Conversely, when there is less head the discharge will be higher than that of the BEP.

Whether or not it is cost effective to correct for a deviation from the BEP depends on the amount of the deviation, the size of the pump, and the cost of power. Small deviations on small pumps typically do not warrant the effort since the savings available is outweighed by the cost. However, the cost effectiveness increases with larger pumps and larger deviations. The actual performance of a pumping system should be field tested to verify that modifying the system is warranted.

When to Have a Pump Test Conducted

Pump tests should be conducted when the monitored parameters of a pump have changed from the normal operating point. These parameters include flow rate, discharge pressure, suction pressure, temperature, and amps. Because performance degrades slowly over time, the changes can easily hide from daily observations. This requires reviewing the recorded data in graphical form, which can reveal subtle trends. Maintaining good equipment records becomes crucial when monitoring trends and the graphs should be updated and evaluated at the end of each month. Pumps that demonstrate a decrease in performance should be tested to verify operating efficiency. Comparing the operating efficiency to the efficiency of the BEP will indicate the savings available. When a significant deviation develops, correcting for a difference between the actual operating point and the BEP can be done by modifying the impeller, pump, or system head.

Field Pump Testing

A flow meter, the pump water level or suction pressure, discharge pressure, input power, and the manufacturer's factory tested pump curve are needed to conduct an accurate pump test under field conditions. Either existing or temporary flow meters and pressure gages can be used provided they are calibrated. If a permanent flow meter is not present a pitot tube or sonic type meter can be used for testing. The meter used must be properly located to prevent turbulence from affecting accuracy. Pitot tubes should be no less than eight pipe diameters from the pump and at least two pipe diameters ahead of any downstream obstructions. The location of sonic meters varies and should be placed per the manufacturer's recommendations. The pumping level and discharge pressure are needed to determine actual lift, which together with the flow rate, will determine the water horsepower (whp). Comparing the whp to the measured input power will indicate the pump system efficiency or how much of the input power is going into water horsepower. Comparing this to the manufacturer's factory tested pump curve will indicate the amount of correction needed.

The electric utility account representative should be contacted whenever pump testing is needed. Many electrical utilities offer pump testing as a service to their larger customers free of charge. The personnel conducting these tests are trained and equipped to conduct pump tests on virtually any type of pumping system. Test reports provided by electric utilities typically include the calculated whp, the measured input power, the operating efficiency, an estimate of the annual electrical consumption and cost, an evaluation of the equipment's condition, and a list of recommended repairs.

Impeller Replacement

The cost to changeout impellers is relatively low and payback periods for these improvements can easily justify the modifications.

Impeller modifications or replacements are an inexpensive change that can alter the operating point of a pump. These changes can reduce pump run times or the need to start additional pumps by increasing a pump's capacity. If the actual flow rate is not too far from the BEP, then it is possible to trim the impeller to improve efficiency. Trimming an impeller reduces its diameter, which decreases the pump's capacity. If the pump's capacity needs to be increased to reach the BEP then the impeller could be replaced. Neither trimming nor changing an impeller is recommended as an adjustment for seasonal changes but rather as a means to accommodate permanent changes in flow.

Several factors limit impeller modifications. For example, impellers must be properly sized for the pump to avoid overloading the motor. The pump curve must be checked to verify that the new configuration will handle the head and that the minimum allowable velocity needed for scour in the discharge piping can be achieved. When trimming an impeller to meet a lower flow it is important to verify the pump station's ability to handle extreme events. Consulting the manufacturer for recommended changes can simplify the process.

Pump Replacement

It is possible to reduce energy consumption by installing new pumps with higher efficiencies. The efficiency of different brands and models varies and, under continuous use, could have relatively short paybacks. Sludge pumps, for example, can vary in efficiency from 35 to 65 percent. Comparing the efficiencies available with the estimated savings will indicate the feasibility of making such a change. The energy assessment should identify candidates for pump replacement.

The effects of a pump change on other process units must be evaluated. For example, plugging of digester heat exchangers is a common problem. Among other things, this can be caused by low velocity. When new pumps are evaluated, verify that the performance of other pieces of equipment, such as the heat exchangers, will not be impacted.

Pumping System Optimization

The energy consumption of a pumping station can be changed by modifying either the pumps or the system to which they are connected. Most pumping stations are equipped with multiple units to handle extreme events. Often the smallest unit available is oversized for the average flow encountered and thus operates inefficiently. The solution can be a smaller pump suited for average or low flow rates. The preceding energy assessment should point out where a smaller pump could be cost effective. If average flows vary significantly, the use of a VFD on the existing pump may be more appropriate.

Reducing discharge head or increasing suction head are system modifications that could reduce the load on a motor. Partially closed valves, sedimentation, corrosion, or scaling will increase discharge head. Similarly, the suction pipe in a wetwell can also become obstructed with debris. It is important to clean out discharge and suction lines when the discharge or suction pressure changes. Removing valves and fittings that are no longer used could reduce the discharge head. Simply increasing the level in a wetwell will improve the suction head and reduce energy consumption.

Maintaining Efficiency

Proper maintenance is needed to prevent performance from deteriorating. Each pump manufacturer can provide a list of standard maintenance practices and intervals for their equipment. These lists typically cover daily observations in conjunction with semi-annual and annual maintenance and inspections. Operators should be alert to the sound of the running pump and to abrupt changes in bearing temperature, stuffing box leakage, and amp readings. Daily monitoring of the pressure gages and flowmeters should be standard procedure. If recording instruments are provided, a daily check should be made to determine whether the flow, pressure, or power consumption require further inspection. If a SCADA system is in place, the system should have built-in alarms to warn operators of potential problems such as motor fail signals generated from thermal overload switches, high bearing temperature, loss of flow, or reduced discharge pressure.

Annual and semi-annual inspections should include routine checks, lubrication, and maintenance. Every six months the stuffing box packing should be checked to see if it needs replacement and gland bolts should be cleaned and oiled. The pump and motor alignment should be checked and adjusted if necessary. Oil lubricated bearings should be checked to see that the amount of grease is adequate and its consistency is suitable.

More detailed inspection and maintenance should be made annually. Bearings should be removed, cleaned, and checked for wear. They should be installed with fresh oil or grease. After disconnecting the motor, the pump shaft should be examined for wear, and the vertical shaft movement should be checked without the packing in place. The stuffing box should be repacked and the driver realigned and reconnected. All instruments should be recalibrated and the system should be tested to see that performance is adequate.

Project Implementation

Predesign

- *Evaluate the results of the pump test.* Compare the pump test results to the BEP on the manufacturer's equipment curve. Determine from the difference what type of modification if any is applicable.
- *Verify assumptions and benefits.* Verify that the values used for calculating the project economics were reasonable. Determine whether run-times, discharge pressure, flow rates, electric rates and demand charges used for calculations are accurate.
- *Verify that critical issues were addressed.* Verify that the proposed project makes sense for the site and application. Verify that the change will not prevent the pumping station from handling extreme events. Verify that the power supply is sufficient for new pumps or that upgrades were included in the feasibility study. Include modifications to the SCADA programming to account for new or upgraded pumps.

Design and Equipment Selection

- *Verify the effects of the change on the pumping system.* Check that a larger impeller will not overload the motor or that a smaller impeller will not prevent the pumping station from handling extreme events. For a new pump, check that the motor control can handle the new equipment.
- *Promote support by operations staff.* Advise and solicit comments from operations personnel. If planning to install new pumps, determine which brands they prefer and whether additional training will be necessary.
- *Quality and performance.* Properly specify the quality and performance of new pumps. Include penalties for not meeting performance specifications.
- *Start-up Services.* Include a requirement for the manufacturer to provide start-up services in the contract specifications. Services should include commissioning, troubleshooting, and training.
- *Warranties and spare parts.* Consider specification of extended warranties for new pumps and provide for spare parts within bid. Use pricing advantage of competitive bidding.
- *System integration.* Require integration of controls with the existing system and any necessary reprogramming of the SCADA system to accommodate the change or addition.
- *Prequalification and references.* For installation of new pumps, prequalify contractors for bidding. Check their references and experience with applicable controls for the particular pump and plant, as well as any specialized qualifications.

Installation Necessities

- Have the contractor perform a preconstruction inventory. It is essential that the contractor be familiar with the scope of work, current facility conditions, and plant operational priorities before installing the equipment.

- Test and report on operation controls before and after work. This will ensure performance is met (or exceeded), while accomplishing energy conservation objectives.
- Confirm accuracy and completeness of preconstruction inventory. Compare results and resolve discrepancies with contract documents.

Start-Up, Maintenance, and Follow-Up Essentials

For a new pump, perform start-up services that include:

- Supervising the start-up with the engineer, contractor, and manufacturer's representative.
- Training staff as required to operate and perform scheduled maintenance of new equipment.
- Troubleshoot the equipment and control system as needed to meet the specifications.

Follow-up items include:

- Monitoring operations to verify performance and collecting data to tabulate savings.
- Preparing final report, including input from Plant Operations.
- Preparing follow-up reports.

Additional Resources

- Water Environment Federation, 1997, *Energy Conservation in Wastewater Treatment Facilities*, Manual of Practice No. MFD-2, Chapter 5.

Pumping Station Modification Checklist

Predesign

- ❑ Determine if the pumping system needs to be field tested.
- ❑ Field test pumps, as necessary.
- ❑ Evaluate the difference between the operating point and the BEP.
- ❑ Determine the proper modification based on the evaluation.
- ❑ Check the economic analysis in the energy study to ensure that it is sufficiently complete.
- ❑ Verify the values and the accuracy of the data used to compute the benefits.
- ❑ Check that the power supply is sufficient for the proposed addition.

Design and Equipment Selection

- ❑ Check that the a larger impeller will not overload the motor.
- ❑ Check that a trimmed impeller will not prevent the station from handling extreme events.
- ❑ Check that the existing motor controls can handle a new pump.
- ❑ Obtain input from operators.
- ❑ Determine if training is required.
- ❑ Include quality and performance specifications for new equipment.
- ❑ Consider including spare parts and extended warranties in bid.
- ❑ Include system integration of new controls.
- ❑ Prequalify contractors and check references.

Installation Necessities

- ❑ Perform preconstruction inventory.
- ❑ Test and report on operation to ensure that the performance specified and energy savings are met.

Start-Up

- ❑ Require contractor to perform start-up services on new pumps.
- ❑ Require contractor to troubleshoot equipment and control integration and submit test reports.
- ❑ Ensure that manufacturer's representative trains operators.

Maintenance and Follow-Up

- ❑ Calibrate control instrumentation and adjust setpoints based on changes in flow pattern.
- ❑ Monitor and collect data to compute savings.
- ❑ Prepare final report.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

7

Cogeneration Optimization

Cogeneration systems at wastewater treatment facilities using anaerobic digestion can reduce the amount of power purchased from the electric utility by up to 50 percent. In some cases, where the nominal plant electric load is unusually low or other low-cost fuels are available, the system may actually generate excess power that can be sold back to the utility. Figure 7-1 illustrates the equipment needed to support a cogeneration system.

Types of Electric Generators

Cogeneration units can typically reduce the amount of power purchased from the electric utility by up to 50 percent.

There are two types of electric generators—synchronous and induction. Synchronous generators have the advantage of operating independent of the utility and, therefore, can be used as standby power during a utility outage. Induction generators are simpler to operate but need a utility power source to supply a reactive load. Several cogeneration systems in wastewater treatment facilities utilize induction generators. Although the initial cost for induction generators is less expensive than synchronous units, they also have an operational cost that synchronous units do not—the electrical utility fee for providing a reactive load.

Types of Prime Movers

Cogeneration systems used at wastewater treatment facilities typically have an internal combustion (IC) engine as the prime mover. Gas turbines should be considered for larger facilities, where the digester gas production is sufficient to generate 2000 kW or more. Facilities should conduct an economic analysis to select the type and size of the prime mover.

The diesel generators commonly used for standby power at wastewater treatment facilities cannot be operated on digester gas. However, diesel generators can sometimes be used for peak shaving, or as a backup when the cogeneration system is down for maintenance. There may be significant air quality issues to address before using a standby diesel generator in this manner.

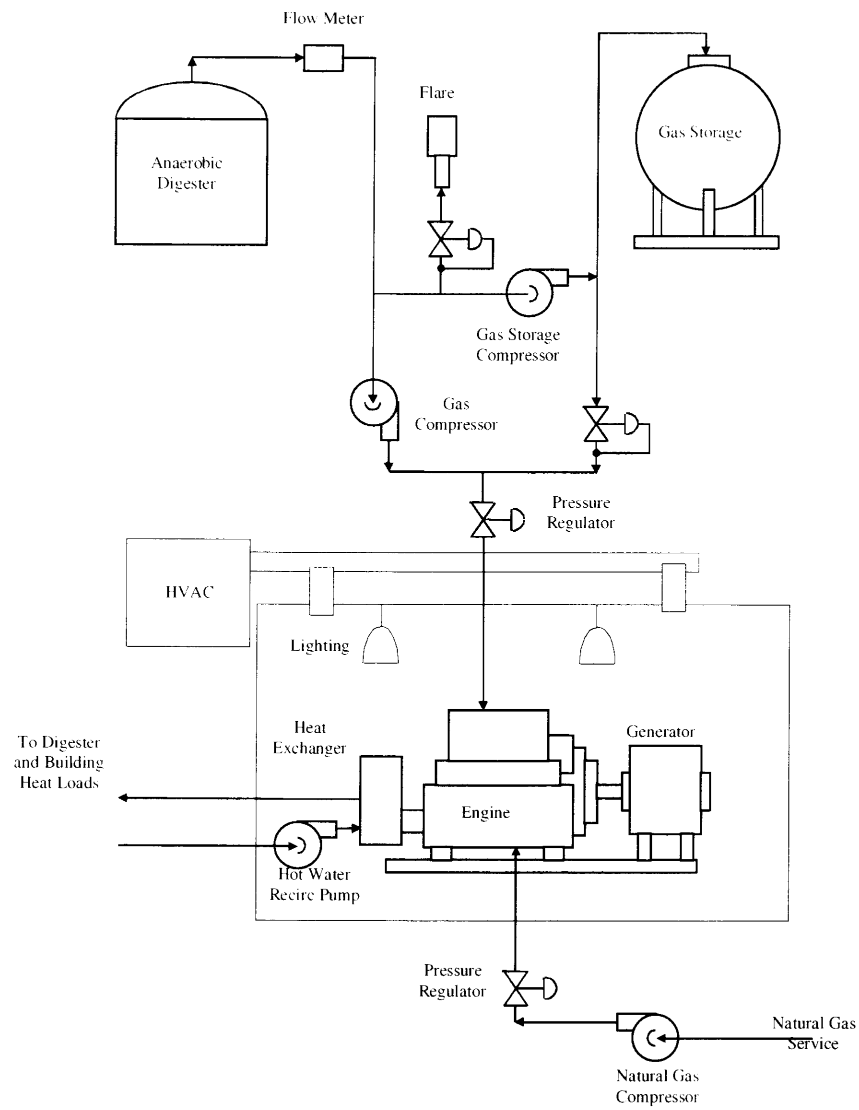

Figure 7-1. Cogeneration Schematic

Sizing a Cogeneration System

Many facilities already have digester gas cogeneration systems and may be discovering that their system has too little or too much capacity. Typically, the design engineer will size the cogeneration system a little larger than the plant's current gas production capacity. Most plants experience some growth each year and the typical life of a cogeneration system is about 20 to 30 years. Usually, several engine/generator sizes are evaluated on a life-cycle cost basis. In some cases, a multiple engine facility will be designed with room for future engines.

Oversized Systems

An IC engine operated too lightly may experience rapid wear on the valves due to insufficient cooling. Also, an engine's efficiency will decrease when it is operated at less than its rated load. Figure 7-2 illustrates the typical performance of a 940-hp (630-kW) engine.

One method of increasing the output of a lightly operated engine is to turn the unit off and store the digester gas during the off-peak periods. Then, start the system during the partial and on-peak periods and operate under more fully loaded conditions. Not only does this allow the engine to be more fully operated, it also will generate more revenue as the value of partial and on-peak power generated is higher than off-peak power. One drawback of this method is that it requires a digester gas storage system. These systems can have a high capital cost and the frequent warm-up and cool-down cycles of the engine can cause increased corrosion from the waste gas.

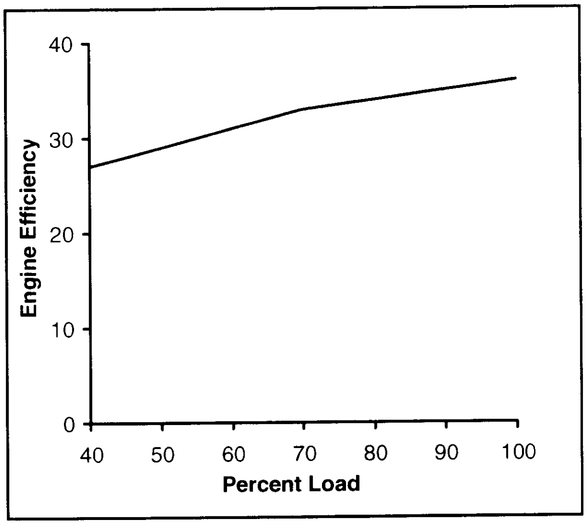

Figure 7-2. Efficiency Curve for a 630-kW, 900-rpm, Low-Speed, Turbo Engine (Source: Waukasha catalog, 5108 GL)

Another option is to supplement the digester gas with natural gas to increase the output of the cogeneration system. The energy content of natural gas is typically about 1000 Btu/cf and digester gas is about 600 Btu/cf. Most cogeneration systems do not operate smoothly or at peak efficiency with a gas supply that varies in Btu content. Systems are available that mix natural gas and air to achieve the same Btu content as the digester gas. The two gas trains can be tied together and the engine will operate smoothly and at peak efficiency on any mixture. A pressure regulator on the natural gas/air line bleeds in the natural gas/air to maintain a constant gas mix pressure. This prevents the digester gas from being accidentally flared. When the digester gas supply is sufficient to fully load the engine, the pressure regulator closes.

Dual gas trains and carburetors allow the engine to operate on either 100 percent digester gas or 100 percent natural gas. This method allows facilities to supplement with natural gas, without the natural gas/air mixing equipment. In this case the engine switches back and forth between the two fuels. A small digester gas storage system may be required, but usually there is enough storage in the digester cover. When these systems are first started up, the transition from one fuel to the next may initially be a bit rough. This can usually be resolved to the point where it is difficult to even hear a difference during a switch.

Using propane as a supplemental fuel has not always worked, due to the much higher Btu content and specific gravity of propane. Digester gas is essentially the same as natural gas—the main fuel component is methane—but propane is chemically different, has different combustion properties, and requires an engine timing change for optimum efficiency.

Undersized Systems

Converting to a turbocharged unit will significantly increase the power output and potentially decrease engine emissions.

A cogeneration system that has too little capacity will not make full use of the available digester gas. This might be the case for an older installation where the plant influent flow has significantly increased.

In this case, it may be possible to increase the unit's output. If it is a naturally aspirated engine, converting to a turbocharged unit will significantly increase the power output and potentially decrease engine emissions. Disadvantages are that the generator will probably require replacement and that the conversion to a lean-burn turbocharged unit is costly. In addition, turbocharged units require that digester gas be pressurized between 40 and 60 psig. Unless gas compression equipment already exists, this cost can be significant.

Another option is to install a second engine-generator. For maintenance purposes, installing a second unit of the same size makes the most sense; however, this may not be the best choice based on the economics. A smaller unit may allow both engines to operate at their peak efficiency. A larger unit may be able to utilize all the gas and allow the existing unit to act as standby.

Having a standby unit, either diesel- or gas-fueled, can be important because the electric utility bill is composed of an energy and demand cost. For most utilities the demand portion is based on the power used during a small time window (15 or 30 minutes is typical)—either the utility's or plant's peak period. If the cogeneration system is down during this period, the plant will be billed for the demand for the entire month. Each utility has various rate schedules and they differ considerably, but typically the demand charges are a significant portion of the electric utility bill. Because cogeneration systems require planned and unplanned maintenance, a single unit is usually not effective in reducing demand charges. Whether it is cost effective to install a second unit solely to save demand charges would require an economic analysis.

Fuels

Digester Gas

Digester gas is essentially a "free fuel," therefore it is beneficial to maximize its production. Digester gas production is dependent upon the digester detention time, digester mixing, raw sludge feed rate, and temperature control.

To maximize detention time, digesters should be cleaned periodically to remove grit that accumulates on the tank bottom. As grit builds up, the effective volume in the digester decreases, which reduces the sludge detention time.

Digester mixing is a double-edged sword. The better the mixing—up to a point—the more efficient the use of the digester volume and the greater the gas production. However, digester mixing requires energy, which decreases the value of the gas production. It may even be more cost effective to turn off the mixing during the on-peak periods and suffer a small drop in gas production! Determining the optimum amount of mixing requires experimentation and an economic analysis.

Digester gas production increases fairly rapidly after being fed raw sludge and this creates the possibility of some crude digester gas production control. However, to be effective there must be a method to store the raw sludge and this can cause process problems. Also, digesters can foam when fed too much in a short period. It is usually best to feed the digesters as frequently and uniformly as possible. Just the daily variations in influent flow cause the digester gas production to be somewhat higher during the partial and on-peak periods.

Digesters provide constant gas production at temperatures of about 90 to 100°F, however, anaerobic organisms are susceptible to rapid changes in temperature. It is best to use an automatic temperature control system where the digester temperature is sampled continuously, or at least once an hour. Manually controlled systems work well as long as the operators are diligent.

A fall-off or surge in gas production is an early sign of a digester in trouble. A good quality gas meter is necessary for each digester, to monitor the gas production for cogeneration purposes, as well as the digestion process. Thermal dispersion meters are the best type for metering digester gas.

Natural Gas

__Most utilities have a cogeneration natural gas rate that can be significantly less than the standard rate.__

Purchasing natural gas to increase the power output of the cogeneration unit can be cost effective. Natural gas cost, avoided power purchase savings, system maintenance cost, and capital improvement costs, if any, are used to determine the cost benefits of supplementing with natural gas. Each cost or savings should be expressed as a cost per kWh and then added together to determine the potential savings.

Natural Gas Cost

The cost of natural gas varies considerably throughout the country. Sometimes it is possible to buy natural gas from a third party at a discount and pay a small transmission charge to the gas utility. Whether this is economical depends on the relative locations of the parties and the amount of gas desired.

Most utilities have a cogeneration natural gas rate that can be significantly less than the standard rate. To qualify, the cogeneration system must typically meet a minimum efficiency and utilize a certain percentage of the input energy for plant heating or cooling. Also, most utilities have a special rate for generators utilizing alternative fuels, and digester gas qualifies as an alternative fuel. With this rate, the natural gas is typically limited to 25 percent of the input fuel. The special gas rates usually require a separate gas meter and pipeline to the cogeneration system. This equipment can increase costs significantly. Some utilities have a curtailable natural gas rate, which could be significantly less than the standard rate.

The natural gas cost per kWh is determined from the engine-generator's efficiency and the conversion between Btus and kWh. Most engine-generators operate at about 30 percent efficiency. The Btu/kWh conversion can be calculated using 3,413 Btus per kWh.

Avoided Power Purchase Savings

For most wastewater treatment facilities, electric power costs vary during the day and seasonally. It may be marginally or not at all cost effective to supplement with natural gas during the off-peak periods but very cost effective during the on-peak period. Each rate period should be evaluated separately.

System Maintenance Cost

System maintenance costs are usually expressed as a cost per kWh and are typically between 0.5¢ to 1.5¢ per kWh. This cost includes items such as engine operator and maintenance time, oil changes, tune-ups, and minor and major overhauls.

Capital Cost

A gas mixing system or other method to allow the engine to utilize natural gas will have a capital cost. Typically this cost is amortized over the life of the system to determine an annual cost and then divided by the yearly power production to determine the cost per kWh.

Landfill Gas

Facilities that are near landfills can sometimes make use of landfill gas (LFG) to supplement their fuel supply. Most landfills are now required to collect and dispose of their LFG and are willing to sell at a discount. There is currently a federal tax credit of about $1 per million Btus available to landfill owners for any landfill gas sold for beneficial use. The gas credit, along with the lack of other uses for LFG, gives landfill owners a strong incentive to deal.

LFG usually requires some cleaning and must be compressed to be transported to the wastewater treatment facility. An LFG scrubbing/compression system typically consists of a venturi scrubber, cooling system (chilled water or DX), and a gas compressor. The venturi scrubber removes particulates and some H_2S and other contaminants, the cooling system dries the gas to prevent condensation during transport, and the gas compressor allows a smaller transportation pipeline to be used.

Often an LFG study is required to estimate the quality and quantity of gas available for the next 20 years before entering into a purchase contract. Landfills start producing gas shortly after refuse is buried. Computer models are used to model the gas production based on the time, type of material, and volume of refuse placed in the landfill. Sample wells are often drilled at several locations of a closed landfill and tested to determine the BTU content and impurities of the gas. This data is used in the design of the gas scrubbing system. Peak gas production is usually not long after the landfill's closure. Since gas production will decline over time, the designer should size the equipment based on the life of the project.

Gas Storage

Digester gas can be stored at high pressure in a gas storage sphere. Effective storage volume is dependent upon sphere volume and the upper and lower storage pressures. Typically these spheres are operated between 40 and 100 psig. There is an energy penalty for compressing the gas beyond what is required for the engine which should be accounted for in the economic analysis.

Other gas storage systems include floating digester covers ("gas holders") and other displacement devices. These systems operate at constant pressure and depend upon volume changes for the effective storage volume.

A decision to provide digester gas storage at the digester is usually made during the design of the digester. It is usually not cost effective to provide a digester gas storage system solely to generate more power during the on-peak and partial-peak periods.

Gas Quality

Digester gas quality will affect the maintenance cost of the cogeneration system. Hydrogen sulfide (H_2S) is the most important impurity in digester gas because it can cause corrosion. Depending upon the treatment processes at the plant, the H_2S in the digester gas may vary from about 100 to 10,000 ppm on a volume basis. Most internal combustion engine manufacturers recommend a limit of 1000 ppm of H_2S in the digester gas.

H_2S has a fuel value that makes it possible to run an engine on 100 percent H_2S! However, H_2S combustion products, when combined with water, form acids that are very corrosive to engine and exhaust systems. The acid is formed when the engine exhaust temperature falls below its dewpoint and water is formed. An important step in reducing corrosion is to operate digester-gas-fueled engines at elevated temperatures.

Another common method to reduce corrosion is to start and stop the engine on 100 percent natural gas. This allows the engine to warm-up and cool down past the dewpoint temperature with no H_2S in the system.

It is possible to remove much or all of the H_2S from the digester gas. There are digester gas scrubbers that will chemically remove all H_2S from the gas. There are several different technologies available, but most plants utilize the iron sponge systems. Today, these systems have the capability to regenerate the media without removal from the tank. However there is a limited number of regenerations possible before the media must be replaced. The volume of media needed depends upon the H_2S concentration in the gas, the gas flow, and the desired time period between regeneration/replacement.

Another method to reduce the H_2S in the digester gas is by adding ferric chloride to the digester (or upstream of the digester). Typically the H_2S is reduced by an order of magnitude or more by the ferric chloride. Some plants have both systems and use ferric chloride to reduce the H_2S to give the iron sponge system a longer life.

Digester gas saturated with water can cause corrosion in the gas piping system. Direct from a digester the gas is usually about 95°F and holds a considerable amount of water as a gas. As the digester gas travels through the piping system it cools down and moisture condenses. Most plants use moisture separators and drip traps to remove the liquid. Some facilities actually chill the digester gas to remove moisture. This ensures that no condensation will occur downstream. Corrosion resistant piping should also be considered.

Heat Recovery

If more heat is required, it is always more cost effective to supplement an engine with natural gas than to utilize a boiler.

By definition, a cogeneration system includes a heat recovery system. For IC engines this usually includes heat recovery from the jacket water and engine exhaust. This heat is used primarily for digester heating, and secondarily for building heating, and in rare cases, for building cooling.

Digester heating demand is composed of heat loss from the digesters and the heat required to bring the raw sludge up to the digester operating temperature. The total heat load is dependent upon the outside air and ground temperature, digester temperature, tank insulation values, raw sludge temperature, and raw sludge flow rate. Typically, for most climates and installations there is enough recovered heat from the cogeneration system alone to meet the digester heating load. If it is insufficient, an auxiliary boiler must be used.

Most plants have standby hot water or steam boilers for digester heating. These systems are utilized whenever the cogeneration system is down or the cogeneration system recovered heat is insufficient.

Any digester gas used in the boiler will not be available for the cogeneration system, so standby boiler use should be minimized. Increasing either the raw solids concentration or the insulation on the digester tanks will reduce the heating demand. Some plants have many different sized digesters and all may not be required to be operated. Note that small digesters have more heat loss per unit volume than large digesters.

If more heat is required, it is always more cost effective to supplement an engine with natural gas than to utilize a boiler. This will increase the natural gas purchases, but this will be more than offset by reduced power purchases. A boiler is about 80 percent efficient and an engine with jacket water and exhaust heat recovery is about 45 percent efficient. This lower efficiency is more than made up by the power generated.

Heat can also be recovered from the engines lube oil cooling system. This is typically at a lower temperature than the jacket water and exhaust but is adequate for building heating.

Load Shedding When Off-Line

All cogeneration systems experience some down time due to planned and unplanned maintenance. For systems without backup generation, a plan that reduces the plant's electrical load until the system is back on line can effectively reduce demand charges. The down time for planned maintenance varies but can usually be scheduled during off-peak periods, which also helps to reduce demand charges.

Load shedding should be practiced when planned or unplanned shutdowns occur. This can be done manually or through a SCADA system. Although it might not be possible to shed enough load to equal that produced by the cogeneration system, this practice will still reduce the demand charge.

Project Implementation

Optimizing a cogeneration system requires an analysis of all or some of the following:

- The plant's electrical load.
- Electricity and natural gas rate schedules.
- Digester gas production rates.
- Digester gas storage capacity.
- Alternative fuels.
- Plant heating loads.
- Cogeneration system capacity.
- Combustion efficiency.

Both projected and current flows and capacities should be considered.

After the projects are identified, evaluated, and selected, they must be described sufficiently to be implemented. Depending upon the nature of the project, this will range from an operational change description to a biddable set of drawings and specifications.

Predesign

- *Include the energy utility's rate schedule in the economic analysis.* The cost of fuel, the avoided electrical purchases, and the O&M costs are the primary factors that determine the economic worth of a cogeneration project. Both energy and demand savings can be achieved, and these savings can vary during the day, as well as seasonally. Most cogeneration projects are decided based on the cost of fuel and power (avoided purchases). Based on the performance of the existing or proposed equipment, the energy and O&M costs and savings are determined and compared to the capital cost of proposed project. From this, a simple payback period or life cycle cost of the project is determined. A report is prepared describing the proposed project and economic analysis. If the economics and level of comfort are sufficient, the project can be implemented.

- *Develop a list of electrical loads to be served.* A list of equipment to be served by the cogeneration unit needs to be created. Characteristics such as load size, load variation, time-of-use, and duty need to be considered.

Design and Equipment Selection

- *Develop preliminary schematics.* A preliminary heat recovery and digester gas schematic should be developed to communicate the proposed project concept to plant managers and staff. A power distribution one-line diagram may also be necessary.
- *Prepare detailed design documents.* For projects requiring system modifications or additions, design drawings and specifications are required. Input from plant operators and maintenance staff during the design process should be encouraged. Preliminary design submittals should be reviewed by personnel familiar with the facilities and operating parameters.
- *Include an adequate training budget.* When preparing specifications, training for operators and maintenance staff should be included in the contractor's scope of work. A classroom-type format for training is desirable, but other formats may be acceptable. Complete documentation on system operation and maintenance should be required of the contractor. The amount of training required will vary depending upon the complexity of the system and the background of the plant staff. Staff skill requirements should be reviewed in order to plan proper training. With complex cogeneration systems it may be necessary to hire additional staff with specific relevant expertise.

Installation

- *Maintain field representation during construction.* An owner representative should be involved in the construction process to ensure that the design intent is being met. The system designer should periodically review the construction, witness the factory tests (if any), and be on site during start-up.
- *Involve operators and maintenance personnel in predesign and construction.* By involving operators and maintenance personnel early, they can begin to develop an understanding of the system and be better prepared to troubleshoot and optimize the system operation. If maintenance personnel are familiar with the equipment, repairs to the system can be made without unnecessary delays and costs for outside services.
- *System testing.* Prior to installation, a factory or field simulation test should be performed, preferably with technical and operating staff present.

Start-Up

- *Verify adequacy of fuel supply and pressure.* For cogeneration systems at facilities with new digesters, complete system demonstration cannot be performed until the digesters are operating. Natural gas can be used to initially perform startup testing but final system operation must be demonstrated with digester gas. If the system has dual-fuel capability, fuel switching without engine shutdown must be demonstrated.
- *Verify operation of heat recovery system.* Startup of the heat recovery system often requires a little fine-tuning to assure adequate cooling of the engine jacket water without wasting excess recovered heat. Sometimes the

system will need "tweaking" as the seasons change. The design engineer should inspect the heat recovery system to verify that it is functioning properly.

Follow-Up

- *Monitor monthly billings to compute savings.* Electrical energy savings, natural gas purchases, and O&M costs should be monitored to determine actual savings. Gas and electrical meters will record the usage and power generated, but the actual value of the power may have to be manually determined due to the time of use rate schedules. O&M costs should be tracked—both materials and contracted repairs and plant staff time.
- *Implement program for continued improvement.* Develop a program that involves the operators in continually monitoring and improving the system.

Additional Resources

- Water Environment Federation, 1997, *Energy Conservation In Wastewater Treatment*, Manual of Practice No. MFD-2.
- ASHRAE Handbook, *Systems*, Chapter 9. 1988.

Cogeneration System Checklist

Predesign

- ❑ Determine whether the proposed cogeneration system operating schemes take full advantage of the energy utility's electric and natural gas schedule.
- ❑ Analyze the cost reduction of a cogeneration gas rate.
- ❑ Determine the amount of digester gas produced that is used for cogeneration.
- ❑ Determine the natural gas savings from heat recovery.
- ❑ Develop a load schedule.
- ❑ Develop a load-shedding scheme for downtimes.
- ❑ Evaluate the ability to operate another engine on excess digester gas.
- ❑ Evaluate the use of backup generators when the cogeneration unit goes down.
- ❑ Assess availability and use of LFG.

Design and Equipment Selection

- ❑ Develop preliminary system schematics prior to detailed design.
- ❑ Consider plant staff input.
- ❑ Develop integration with plant SCADA system.
- ❑ Consider using the SCADA system to shed load when engine is down.
- ❑ Include adequate training budget for operators in the Contractor's Scope of Work.
- ❑ Collect quotes from at least three manufacturers.
- ❑ Check references of similar projects.
- ❑ Specify the support and service level required of the manufacturer.

Installation

- ❑ Maintain field representation during construction.
- ❑ Involve operators and maintenance personnel in predesign and construction.
- ❑ Require factory tests with involvement from the design engineer and operators.

Startup

- ❑ Ensure adequate fuel supply and pressure.
- ❑ Verify that instruments have been calibrated properly and checked after installation.
- ❑ Ensure adequate waste heat cooling capacity.
- ❑ Test back-up fuel supply.

Follow-Up and Maintenance

- ❑ Monitor monthly fuel billing and electricity and O&M cost savings to compute actual savings.
- ❑ Implement program for continued improvement.
- ❑ Check instrument calibration regularly.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

8

Retrofitting Aeration Systems

Biological treatment of municipal wastewater, conducted in the activated sludge process, is vitally dependent on the concentration of dissolved oxygen (DO). Microorganisms that degrade the waste through aerobic respiration use DO in the wastewater for growth and development. Oxygen is also used to mix the contents of the aeration basin to keep the microorganisms and the organics in suspension. In most cases, the oxygen required for degradation is sufficient to satisfy mixing needs. Therefore, oxygen requirements usually depend directly on the strength of the influent and the amount of degradation required to achieve a high-quality effluent. These requirements will vary in time and in location depending upon the season, time of day, water source, industrial presence, and the weather. In total, aeration systems can demand as much as 60 percent of the plant's total electricity use and, therefore, are prime targets of an energy reduction program.

Optimizing an aeration process requires evaluation of all the parameters associated with the aeration system. These parameters include the wastewater characteristics and biological loading in the basins, method of oxygen transfer, type and size of the air supply equipment, method of controlling the air supply, and maintenance of the equipment. Reducing the biological loading through improved primary clarification is discussed in Chapter 10, Alternatives for Managing Plant Loading. Improving the oxygen transfer efficiency, properly sizing and controlling blowers, and the maintenance necessary to maintain efficiency is discussed below.

Benefits of Fine-Bubble Diffusers

For certain applications, fine-bubble aeration systems have gained widespread acceptance as a means of reducing the electricity demands of aeration systems because of the higher oxygen transfer efficiencies achieved. Fine-bubble diffuser manufacturers contend that on a per-pound-of-air-delivered basis, fine bubbles have a greater surface area with which to transfer oxygen into wastewater. Thus, they argue, oxygen transfer efficiency—a measure of the mass of oxygen transfer per scfm of air delivered—increases with the use of fine-bubble diffusers. With less air required to deliver the same mass of oxygen, operators may be able to adjust blowers to a lower level. Because both blowers and mechanical aerators are typically powered by a large motor, adjusting them to a lower level will directly reduce the power drawn and, accordingly, electrical costs. As a result of this greater efficiency, some plants have begun to retrofit both mechanical aeration systems and older coarse-bubble aeration systems with fine-bubble systems.

Types of Fine-Bubble Systems

Aeration systems demand as much as 60 percent of the plant's total electricity.

Diffused aeration systems pump air from blowers through drop pipes that descend into an aeration basin, through laterals which run the length of the basin, and ultimately out through porous assemblies called diffusers. The size of the air bubbles emitted from the diffusers largely determines whether a system is classified as fine-bubble or coarse-bubble.

Various manufacturers have developed a number of different diffuser assemblies for fine-bubble aeration. Figure 8-1 shows a membrane diffuser. Membrane diffusers are primarily constructed by stretching porous EDPM rubber over a fixed plate, which is then attached to a PVC lateral. Figure 8-2 shows ceramic disc diffusers that are similarly attached to a fixed plate, but do not maintain the same cleaning requirements.

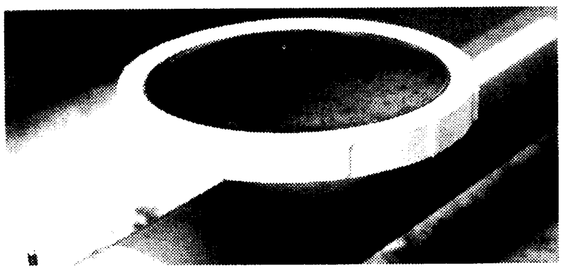

Figure 8-1. Fine-Bubble Membrane Diffuser, courtesy of *Sanitare*

Membrane tube diffusers, shown in Figure 8-3, are, as the name implies, porous tube assemblies which are attached to the laterals.

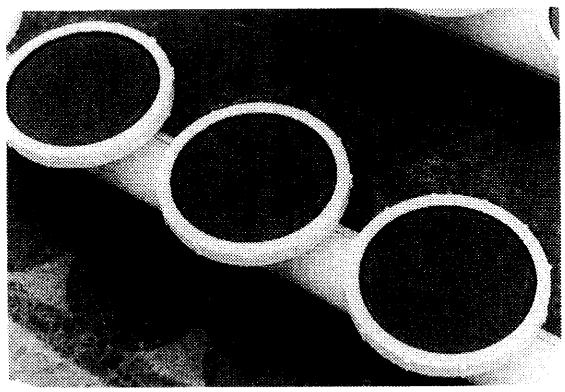

Figure 8-2. Fine-Bubble Ceramic Disc Diffuser, courtesy of *Sanitare*

Panel diffusers, shown in Figure 8-4, consist of a proprietary plastic stretched across a stainless steel frame approximately 4 feet wide by 12 feet long. Functionally, they operate much like membrane diffusers in that they are typically placed a foot above the bottom of an aeration basin and are supplied by air from a blower.

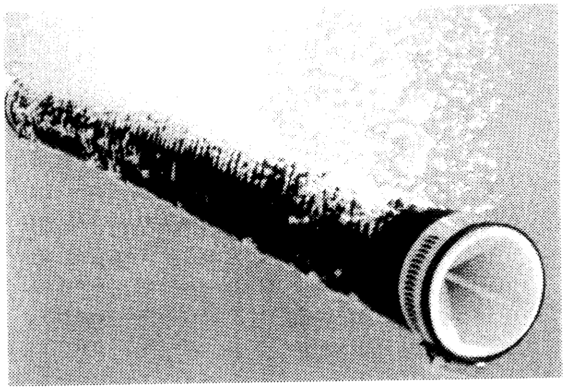

Figure 8-3. Membrane Tube Diffuser, courtesy of *Parkson*

The manufacturer of the panel diffuser contends that the panels maintain an even higher oxygen transfer efficiency than traditional fine-bubble membrane diffusers. One possible reason for the reportedly higher values may be the increase in the diffuser area relative to the aeration basin floor (diffuser density.) Some argue that by placing more membrane diffusers in an aeration basin to achieve a greater diffuser density, one could achieve results similar to panel diffusers.

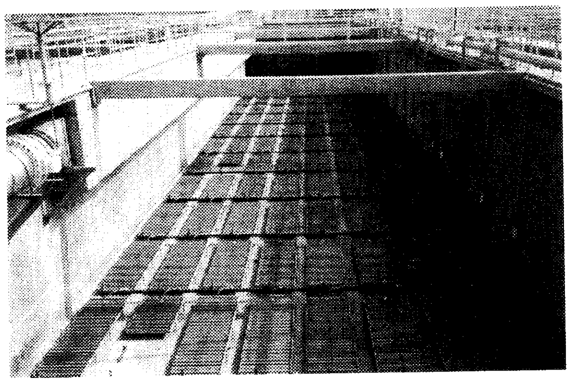

Figure 8-4. Panel Diffusers, courtesy of *Parkson*

However, replacement costs for the panels when they are stretched or degraded beyond usefulness, may be greater than those for membrane diffusers. In addition, the capital costs of panel diffusers may be greater than those of other fine-bubble diffusers. Each of the four forms of fine-bubble diffusers offer similar performance but have vastly different maintenance requirements. Maintenance requirements are discussed further in this section.

Blowers

The term *blower* generally applies to equipment that delivers air at pressures up to 15 psi. Typically, only two types of blowers are used in wastewater aeration: rotary positive displacement units and centrifugal units (both single- and multi-stage).

The capacity of any blower can be defined in several different ways but should reference inlet conditions for proper selection. Thus, capacity is most easily referenced as inlet volume per minute (cfm, icfm, or acfm). Positive displacement blowers are typically available in capacities of 5,000–50,000 acfm, while centrifugal blowers can be obtained in capacities ranging from 500–150,000 acfm.

Positive displacement blowers can operate over a range of discharge pressures and deliver high-efficiency output. However, unlike centrifugal blowers, they cannot throttle airflow rate, although the blowers can be speed controlled. In addition, positive displacement blowers may require a more substantial foundation to dampen noise and vibration, and generally may be noisier than centrifugal blowers.

Although centrifugal blowers may be quieter and require a less substantial foundation than positive displacement blowers, they can only operate over a limited range of discharge pressures and may deliver a reduced volume of air if diffusers are plugged.

The ability of existing blowers to efficiently produce air must be evaluated whenever the biological loading in the basins is reduced or the type of diffusers are changed. Reducing the amount of air required through these methods only reduces energy consumption if the blowers can turn down to match the new demand. If unable to turn down, the excess air produced will appear in high DO readings. The preceding energy audit should indicate whether a smaller blower is required to capture the energy savings. Furthermore, a change to fine bubble diffusers will likely increase the system pressure. The existing blowers must also be evaluated for the ability to handle higher pressures.

Mechanical Aeration Systems

Instead of coupling blowers with diffusers, some wastewater treatment plants use mechanical aeration systems to supply oxygen. Surface aerators, which violently mix the contents of an aeration basin, causing tiny wastewater droplets to be thrown into the air where they can contact and absorb oxygen, represent the most common form of mechanical aeration.

Generally, mechanical aeration systems are less energy efficient than diffused aeration systems.

Generally, mechanical aeration systems are less energy efficient than diffused aeration systems. However, when it is infeasible or impractical to replace a mechanical aeration system with diffusers, some energy savings may be obtained by adjusting impeller height (in the case of a low-speed surface aerator), or by using a dual-speed or variable-frequency-driven motor (in the case of a high-speed surface aerator). In the latter case, when high aeration levels are not required, the speed of the aerator—and thus the energy requirements—can be reduced.

Operations and Maintenance Issues

Diffusers and DO probes operate in a harsh environment that exposes them to a variety of elements, which can reduce their performance. Damaged air filters and corrosion in the air piping can foul diffusers from the inside. Bacterial growth on the outside creates the same problem. A significant number of fouled diffusers will increase header pressure and decrease the performance of the activated sludge process.

Similarly, DO probes can be fouled by stringy material suspended in the basin or bacterial growth. Many probes need to be calibrated frequently and have parts that require scheduled replacement. Probes that are not maintained produce erroneous readings that affect how closely the output of the blowers match the actual oxygen requirements in the basins.

Air filters should be replaced and both DO probes and diffusers must be cleaned regularly to avoid fouling or plugging. Hypochlorite is often used to clean diffusers, which requires the basin to be removed from service. Proprietary chlorine gas systems are available that allow the diffusers to be cleaned without removing the basin from service. DO probes should be cleaned as recommended by the manufacturer. The time between probe cleanings varies depending on the type of probes used. Several brands require frequent calibration and cleaning while others are self cleaning. Although the self-cleaning probes are typically more expensive, when labor is considered, they have a relatively short payback. Cleaning diffusers and probes is important and must be conducted at regularly scheduled intervals to maintain optimum efficiency.

Automated Dissolved Oxygen Control

Maintaining the correct amount of oxygen is critical to the sustenance of the microorganisms and the biological treatment process. Most aeration systems can supply enough oxygen to saturate the entire wastewater stream, to ensure that the organisms will have enough oxygen to grow. Using this strategy, plant operators set the aeration system at a predetermined air flow rate based on experience and do not vary oxygen supply over time. Oftentimes, however, the microorganisms will not be able to use all of the oxygen supplied. Although this strategy appears harmless, the blowers that supply the air require a great deal of power. The more oxygen left unused in the biological treatment process, the more power (usually electricity) is wasted.

In an effort to match oxygen supply with demand, some wastewater treatment facilities attempt to monitor the concentration of dissolved oxygen (DO) in the wastewater. When concentrations fall below recommended limits, the blower system is turned up to distribute more oxygen into the aeration basins. Conversely, when the concentration of DO rises, the blower system is turned down to accommodate a decreased demand for oxygen and to save energy. If the DO concentration is not maintained at the proper level, the system will exhibit anaerobic conditions. This, in turn, will cause a plant upset, disrupt the biological treatment, produce noxious odors, and potentially may violate the discharge permit.

Facilities typically employ two methods to avoid plant upsets and properly maintain DO levels. In the first method, plant operators periodically take samples of the aeration basin wastewater and measure the DO level—either by using a handheld device called a *DO probe* or by using standard laboratory titration procedures. Plant operators can then compare laboratory results to recommended DO levels and manually change the blower setting to compensate for disparities between projected needs and actual performance. Because it is impractical to take readings often enough to measure DO this way, operators rarely turn blowers down. In most cases, blowers are set at a predetermined level and only adjusted to account for "slug" loads of high-strength waste influent that enters the treatment facility. In these cases, the DO measurement is used as a process check to ensure that it is operating within prescribed limits and that no major adjustments need to be made.

The second method employed by some wastewater treatment facilities uses DO probes that are "permanently" placed in the aeration basin to continuously monitor DO levels. In some cases, these probes provide continuous readouts that allow operators to manually adjust the blowers on a regular basis. Because reading the DO concentration in the aeration basin requires less time with continuous DO probes than with other methods, blower adjustments are typically made more frequently. This enables the operator to more closely control the process and reduce energy costs by a substantial margin.

In some configurations, DO probes can be connected via an instrumentation panel or SCADA system to automatically control the blowers. The system then automatically adjusts blower output at preset time intervals based upon a comparison between an average of DO readings in the aeration basins and a programmed, recommended DO concentration. Automatic adjustment helps to conserve energy during periods when the influent wastewater does not contain a high biochemical oxygen demand (BOD) concentration and helps the biological treatment process function more effectively when high BOD levels are present. The continuous control enables the plant to more closely match oxygen supply with oxygen requirements. As a result, less energy is wasted and plant upsets are avoided when receiving high-strength slug loads.

Regardless, if the DO concentration is regularly monitored, operators can pursue a different control strategy for each type of blower. If mechanical aerators are used and dual-speed or variable-frequency drive motors are in place, the speed of the motors can be reduced when influent loads decrease. If centrifugal blowers are used, operators can throttle inlet guide vanes or inlet valves to reduce power consumption. If the facility uses positive displacement blowers with variable-frequency drives, the speed of the motor and the blower output can be reduced to match oxygen requirements of the influent. Using any of the three strategies, operators can use the data from the DO probes mounted in the tanks to manually or automatically control the blowers more closely.

Given the potential energy savings associated with automated dissolved oxygen control, it should be considered in cases where aeration basins are being retrofitted with fine-bubble diffusers.

Project Implementation

Predesign

- *Determine wastewater characteristics.* Any aeration design should carefully consider the characteristics of wastewater for a particular facility. At a minimum, the design should consider annual average, maximum monthly, and peak day mass loadings of BOD, total suspended solids (TSS), and total

Kjeldahl nitrogen (TKN). Minimum and maximum wastewater temperatures are also critical parameters. Another consideration is the presence of industrial contributors and their potential affect on the determination of the alpha factor, which is the ratio of oxygen transfer efficiency in tap water to that in wastewater. As an example, the presence of a soap or surfactant manufacturer discharging into a municipal sewer can lower the alpha factor used in the design. These constituents tend to impede oxygen transfer and can cause foaming when fine-bubble diffusion is used. As another example, high carbonate levels in the influent levels may cause ceramic disc diffusers to foul more easily.

- *Consider methods of reducing the biological loading in the aeration basin.* The amount of oxygen required is proportional to the biological load to be treated. Reducing the load will decrease the energy used in the process. Industrial pretreatment programs and improved primary clarification are two methods that could reduce aeration energy. Further discussion on improving performance of primary clarifiers is discussed in Chapter 10.
- *Determine the correct alpha factor.* In the design phase, consider that the alpha factor will vary with the amount of organics present in the water. Such variation should be strongly considered in a high loaded system, plug flow reactor, and a nitrifying or complete nitrogen removal design. If a higher-than-expected net transfer efficiency is achieved in the field and the blowers cannot be sufficiently turned down, any recycle directed to an anoxic basin may have a residual DO level that exceeds recommended limits of a denitrification process.
- *Determine the fouling factor.* Fouling normally decreases the oxygen transfer efficiency by changing the size and shape of the air bubbles. For new diffusers the fouling factor is 1.0 (i.e. zero fouling) but over time it decreases. The factor is used to address both biological fouling and material fatigue. Biological fouling is temporary and can be corrected when the diffusers are cleaned. Material fatigue is a permanent change to the diffuser that can only be corrected with replacement. Like alpha, the fouling factor must be considered during design to properly size an aeration system.
- *Determine whether the basin is oxygen- or mixing-limited.* During the planning or conceptual design phase, ensure that the aeration basin is oxygen-limited and not mixing-limited. Should the mixing requirements dominate, the air added to keep the mixed liquor in suspension will supply sufficient oxygen. Thus, facilities may not achieve the potential electricity savings realized by more efficient fine-bubble diffusion.
- *Consider patent protection issues.* The acid gas cleaning system used for ceramic fine-bubble diffusers is protected by manufacturer patents. Users of such a system may be required to pay royalties to the patent owner for its use.

The method of cleaning fine-bubble diffusers must be considered in the design.

- *Consider cleaning and maintenance issues.* To maintain optimal performance, operators must periodically clean DO probes and ceramic diffusers and replace membrane diffusers. Typically, ceramic diffusers are cleaned with a chlorine gas system. Given the hazards of using chlorine gas, some facilities decide that ceramic diffusers are not a viable alternative. Additionally, because membrane diffusers can deform over time, they must be periodically replaced. Although the frequency of replacement will vary with the site and equipment-specific operating conditions, as a rule-of-thumb the expected lifetime of a membrane diffuser is 5 years. Membrane diffuser replacement should therefore be considered during the planning phase. The frequency for cleaning DO probes varies depending on brand and site conditions. Consult the manufacturer for recommended schedule and procedures.

- *Consider the potential for foaming.* Fine-bubble diffusers used in post-aeration of highly treated effluent have been noted to sometimes cause foaming. This phenomenon appears to be more prevalent with trickling filter effluent. The potential problems associated with remedial measures for foaming should be evaluated in the design.

- *Consider the effects of grit.* Installation of membrane-type diffusers in aeration tanks without primary clarifiers or effective grit removal systems upstream can experience excessive wear and failure of membrane material. Grit removal should be addressed.

Design and Equipment Selection

- *Check current conditions.* Consider the relation of current flows and loads to those of design conditions. If they differ significantly and provisions are not made to accommodate the difference, cost savings or performance may suffer.

- *Consider seasonal variations.* In situations where seasonal variations cause operators to regularly take an aeration basin out of service, consider the effect on any aeration system. If an aeration basin is not completely drained when taken out of service, fine-bubble diffusers have a greater tendency to plug than coarse-bubble diffusers. Also, when basins are completely drained, laterals pipes made of PVC may not maintain adequate resistance to the sun's UV radiation.

A change from coarse-bubble to fine-bubble diffusers may require installation of at least one additional smaller blower.

- *Ensure adequate blower turn-down.* Potential energy savings associated with higher oxygen transfer efficiency may be lost if blowers cannot be turned down or adjusted to meet oxygen demands. Check blowers for average and minimum flow conditions. Often a change from coarse-bubble to fine-bubble diffusers may require installation of at least one additional smaller blower.

- *Ensure that blower discharge pressure is adequate.* Generally, a greater discharge pressure is required to overcome the greater resistance of fine-pore diffusers over and above that required for course-bubble diffusers. Thus, the designer should check that the discharge pressure is adequate to overcome headloss through the diffusers, associated piping, and the head of wastewater in the basin. Note that the ultra-fine-bubble panels have a higher headloss than the conventional fine-bubble systems.

- *Check the minimum air flow required for the diffusers.* Consult the diffuser manufacturer for the minimum air flow rate per diffuser. When the flow rate drops too low in membrane diffusers, the distribution of air in the basin becomes uneven. In other diffusers wastewater can backflow into the diffusers, thereby clogging the pores.

- *Consider adding automated DO control.* When replacing any aeration system with fine-bubble diffusers, consider the addition of variable capacity blowers and automated DO control. If designed, built, and used properly, such a system can yield significant electrical savings. Incorporating this into the plant SCADA system will provide real-time data to assist in troubleshooting and to use in reports. The capital costs of automated systems can be offset by these electrical savings, particularly at larger facilities. A present-worth economic analysis will help clarify whether automated control has the potential to yield cost savings above its initial capital cost.

- *Check the design operating temperature of the blowers.* Ensure that the blowers are properly designed and rated for the maximum operating temperature conditions expected on-site. If blowers experience higher-than-designed-for temperatures, performance of the blowers—and thus the biological treatment system—cannot be guaranteed.
- *Check the geometry of the aeration basin.* Sloped walls may be adequate for mechanical aeration but are decidedly inadequate for diffused aeration as they prevent full floor coverage by the diffusers and create dead spots.
- *Consider basin shutdown situations.* Overpressurization of the diffusers may occur when one or more aeration basins are taken out of service and the remaining air and pressure are diverted to other basins. The additional pressure may stretch the EPDM rubber of membrane diffusers. In some cases, the EPDM rubber may not return to its original shape, its pores may permanently widen, and it may lose the oxygen transfer efficiency it once maintained.

Installation Necessities

- *Ensure adequate protection for piping.* In some cases there may be long piping runs from a remote blower building to the aeration basin. Any piping runs should be adequately protected from pedestrian or motorized traffic so that the pipes are not ruptured.
- *Ensure that PVC laterals are not exposed to sunlight for extended time periods.* Over time, sunlight can degrade the PVC laterals that are common in fine-bubble systems. If construction is expected to take a long time, ensure that any stored or installed PVC pipe is protected from sunlight.
- *Provide easy access to DO probes.* The efficiency of an automated system depends on the accuracy of the data collected. DO probes require scheduled cleaning to maintain their performance. Mounting the probes in an easily accessible location facilitate this maintenance.

Start-Up, Maintenance, and Follow-Up Essentials

- *Perform pre-startup services immediately upon installation.* Supervise final adjustments, calibrate the equipment, including any dissolved oxygen probes, and check to ensure that the installation was completed adequately.
- *Conduct a performance test of the aeration equipment.* If conducted immediately upon start-up of the aeration basin, while filled with water only, such a test will help ensure that the system delivers the volume of air required at the specified discharge pressure and at the estimated oxygen transfer efficiency. These performance tests will enable an end-user to determine whether the purchased fine-bubble diffusers are as efficient as they were purported to be and, therefore, will help determine whether the anticipated energy savings are likely to be realized.

- *Perform startup and demonstration services.* Require the contractor/vendor to conduct the startup of all units, with complete recheck of final adjustments, calibration, and commissioning. Have work performed in the presence of the wastewater utility's representative(s).

- *Ensure DO probes are calibrated regularly.* To a certain extent, all DO probes tend to "drift" and should be recalibrated regularly. If this is not accomplished, the result can be inaccurate readings that cause unnecessary or improper adjustments in airflow rates.

- *Ensure that diffusers are cleaned or replaced as needed.* Over several years, fine-bubble diffusers may foul, plug, or stretch. If these problems become excessive, the oxygen transfer efficiency decreases, along with energy savings. Facilities should establish and follow a routine inspection, maintenance, and cleaning procedure.

Additional Resources

- Water Environment Federation, *Design of Municipal Wastewater Treatment Plants*, Manual of Practice, No. 8, 1992.
- Water Environment Federation, *Energy Conservation in Wastewater Treatment Facilities*, Manual of Practice MFD-2, 1997
- Tchobanoglous, G. and F.L. Burton, *Waste Engineering: Treatment, Disposal, Reuse*. Metcalf & Eddy, 1991.
- EPRI Community Environment Center: *Review of Dissolved Oxygen Monitoring Equipment*, Report CR-106373, April 1996.w
- EPA, *Fine Pore Aeration Systems*, EPA 625/1-89-023, September 1989.
- EPRI, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*, Report CR-106941, September 1996

Aeration System Retrofit Checklist

Predesign

- ❑ Determine the characteristics of the facility's influent wastewater loading.
- ❑ Consider methods of reducing the biological loading in the aeration basins.
- ❑ Determine the presence of certain industries, such as soap or chemical manufacturers, that may impact the selection of an aeration system.
- ❑ Conduct a preliminary design to estimate blower and diffuser requirements.
- ❑ Evaluate the need for a new, smaller blower.
- ❑ Ensure that the aeration basins are not mixing-limited.
- ❑ Include fees for patent royalties.
- ❑ Plan for cleaning and maintenance requirements.
- ❑ Address potential foaming problems.
- ❑ Evaluate the potential for grit damage on membrane diffusers.

Design and Equipment Selection

- ❑ Provide for future design loads.
- ❑ Evaluate the effects of seasonal flows on diffusers.
- ❑ Ensure that the selected blowers can be "turned down."
- ❑ If existing blowers will be used, ensure that the discharge pressure is adequate for the proposed fine-bubble system.
- ❑ Check minimum air flow rate for diffusers
- ❑ Incorporate automated DO control into the system.
- ❑ Ensure that the maximum operating temperature is within the range of the blower(s).
- ❑ Account for sloped wall basin irregularities.
- ❑ Design for basin shutdown situations and current loadings.

Installation Necessities

- ❑ Ensure that piping is adequately protected.
- ❑ Protect PVC lateral from prolonged exposure to UV.
- ❑ Provide easy access to DO probes.

Start-Up, Maintenance, and Follow-Up Essentials

- ❑ Calibrate and debug all equipment and operating systems.
- ❑ Require vendor to conduct a performance test to verify conformance with specifications.
- ❑ Have vendor conduct demonstrations and training for staff as necessary.
- ❑ Establish a schedule for DO probe calibration.
- ❑ Create a preventative maintenance program for the blowers and diffusers.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

9
Ultraviolet Disinfection

Ultraviolet (UV) radiation in wavelengths ranging from 250 to 270 nanometers is readily absorbed by deoxyribonucleic acids (DNA). When this energy is absorbed by DNA, its molecular structure can be altered, resulting in a loss of ability to replicate. While this effect can be reversed (referred to as reactivation), UV radiation is effective in inactivating certain pathogens found in municipal wastewater. For this reason, UV lamps that have an output in this range can be used for disinfection.

Benefits of UV Disinfection

UV disinfection has several advantages when compared to other disinfection alternatives. Unlike chlorination and ozonation, UV disinfection is a physical process that does not involve the addition of chemicals. As a result, UV disinfection does not produce toxic residuals or form known byproducts that pose a risk to humans or aquatic organisms. In contrast, many municipalities are being required to remove residual chlorine before discharging treated wastewater due to concerns over chlorine's toxicity to aquatic life, which requires the addition of sulfur dioxide or other reducing agents (resulting in additional costs). Discharge permits that include Whole Effluent Toxicity (WET) testing effectively act to reduce or eliminate chlorine residuals in the discharge from wastewater treatment plants.

Another benefit of UV disinfection is that it eliminates the need to transport and handle potentially dangerous chemicals. While this is primarily a safety issue, there are also costs associated with such transport and storage. The 1988 Uniform Fire Code (and subsequent revisions) includes requirements for the control of accidental discharges of gaseous chlorine. The scrubbers required to meet these codes increase capital costs for chlorine disinfection systems. Since UV disinfection facilities do not require scrubbers and occupy only minimal building space and basin volume, UV disinfection is often found to be a viable, cost-effective alternative to chlorination and ozonation.

Types of UV Systems

There are several UV system design issues to be considered: lamp pressure (low or medium); lamp configuration (horizontal or vertical); whether to use an open channel or closed vessel; and the various cleaning methods involved.

Low-Pressure Systems

Low-pressure UV systems have a proven track record for groundwater and wastewater disinfection. Open-channel, low-pressure systems predominate by far in the United States. In a 1990 survey, 98 percent of all the UV systems used low pressure lamps. Table 9-1 summarizes low-pressure UV operating characteristics. Low-pressure UV lamps have a near monochromatic output at

253.7 nanometers, which makes them ideal for disinfection. Improved reactor design, cleaning techniques, control systems, and lamp and ballast configurations over the last several years have made UV technology more energy-efficient and maintenance-friendly while reducing capital costs.

Table 9-1. Operating Characteristics of Low- and Medium-Pressure UV Lamps

Variable	Low-Pressure UV Lamps	Medium-Pressure UV Lamps
	Range of Operation	
Emission Wavelength	near monochromatic at 254 nm (~85% at germicidal range)	broad spectrum (10–60% at germicidal range)
Power Conversion to UV (%)	35–40	15–25
Typical Number of Lamps (#/mgd)	40–60	2–4
Typical Power Use (kW/mgd)	3.2–4.8	6.8–15
Minimum Lamp Life (hours)	> 8,760	2,000–5,000

A low-pressure UV system consists of a power supply, ballasts, lamps, reactor, cleaning equipment, and controls and instrumentation. Low-pressure lamps operate at a temperature range from 100 to 120°F and typically last a minimum of 8,760 hours.

Although conversion of applied power to UV radiation is typically only between 35 and 40 percent, nearly 85 percent of these emissions are at germicidal UV wavelengths. As a first estimate, between 40 to 60 low-pressure lamps per mgd can be used for system sizing. These values are appropriate for disinfecting a good quality, biologically pretreated wastewater (with a minimum design transmissivity of 65 percent) to comply with an effluent limit of 200 fecal coliforms per 100 mL.

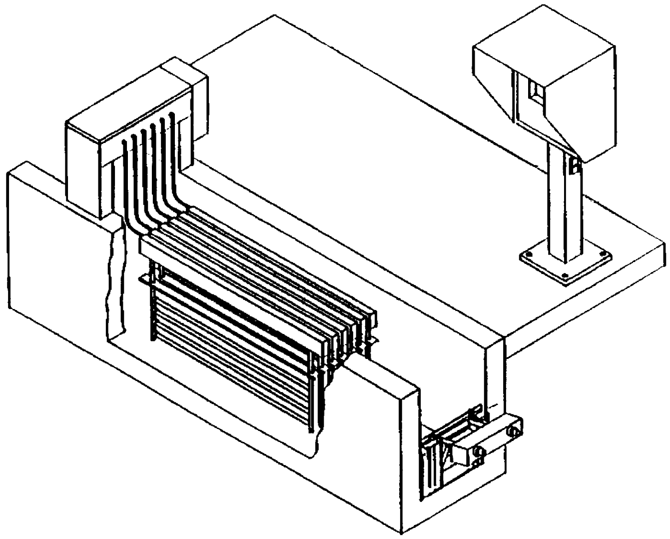

Figure 9-1. Open-Channel, Horizontal UV Disinfection System, courtesy of Trojan Technologies

The majority of the low-pressure systems currently specified for wastewater treatment consist of lamps suspended in an open channel. The open-channel design offers an economic advantage where the UV system is retrofitted into an existing treatment plant. At many wastewater treatment plants, an existing basin can be converted to an open-channel UV reactor at minimal cost. The lamps are placed in the channel either horizontally or vertically. An example of a horizontal system is shown in Figure 9-1 and a vertical system in Figure 9-2. In the most widely used system, lamps are mounted on removable racks which are suspended in the open channel; allowing the lamps to be removed for cleaning and replacement. By using multiple banks of lamps and multiple channels, maintenance can be performed without affecting treatment capacity. Depending on the ballast and lamp arrangement, low-pressure systems typically consume 65 to 90 watts per lamp. Using 40 to 60 lamps per mgd, the power requirement of a low-pressure UV system for wastewater treatment will be 3.2 to 4.8 kW/mgd. The actual power use per mgd will be a function of the number of lamps in service. To conserve energy, the number of lamps in service can be paced to the flow rate of wastewater. Controlling the number of lamps based on both flow rate and transmissivity offers more energy savings by shutting off lamps when wastewater quality is improved.

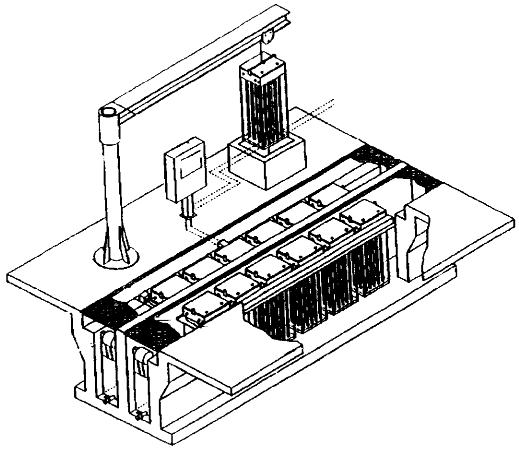

Figure 9-2. Open-Channel, Vertical UV Disinfection System, courtesy of Infilco Degremont, Inc.

Medium-Pressure Systems

Medium-pressure UV lamps emit radiation in the germicidal range at a much higher intensity than low-pressure lamps. While this is an advantage for medium-pressure systems (because fewer lamps are required to apply the same UV dose) the medium-pressure lamp is much less energy-efficient than the low-pressure lamp in converting electric power to germicidal radiation. The two leading suppliers of this technology account for a total of only 16 medium-pressure systems for wastewater treatment in North America, however, this number is rapidly increasing. As of January 1998, 76 full-scale medium pressure UV systems were in place or had been shipped to the North American wastewater disinfection market. Many more installations are in the planning and design stages. A summary of medium-pressure UV operating characteristics is given in Table 9-1. Figure 9-3 illustrates a typical medium-pressure layout. The basic components of a medium-pressure UV system are a power supply, transformers, capacitors, UV lamps, and reactors. Both of the two leading suppliers provide a medium- and high-power setting on the transformer to allow the lamps to be dimmed to approximately 60 percent of their maximum power use during periods of low flow or high water quality. This feature permits a more energy-efficient operation and can extend lamp life.

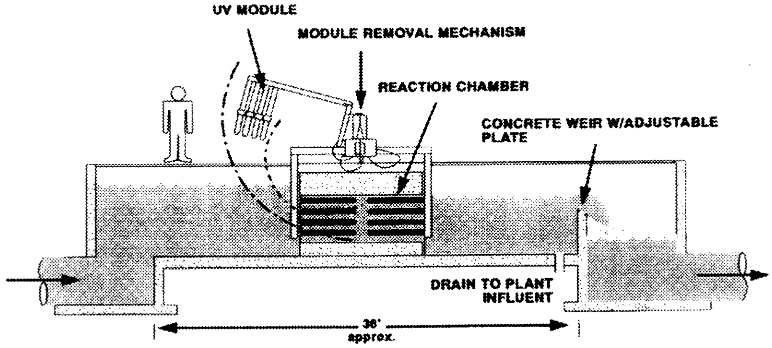

Figure 9-3. Medium-Pressure UV Operating System, courtesy of Trojan Technologies

Presently, manufacturers guarantee a minimum lamp life between 2,000 and 5,000 hours at the high-power setting. Due to their high intensity, it is suggested that one medium-pressure lamp can replace 6 to 16 low-pressure lamps, depending upon design conditions. One supplier suggests a rule-of-thumb number of four lamps per mgd. At 2.5 kW per lamp, the power draw would range from 6.8 to 10 kW per mgd (using a minimum power setting of 68 percent of full power). As wastewater quality decreases, the kilowatts per mgd rises. At a 50 percent transmissivity, the power draw would increase to between 13.4 and 15 kW per mgd. Medium-pressure systems are available in closed-chamber, closed-channel, and open-channel designs, with an automated wiper system to clean the lamps. The closed-chamber design is used for flows less than 5 mgd. The open-channel design is presently marketed only for flows of 10 mgd and higher. The wipers travel along the length of the lamp at timed intervals to remove deposits before they become tightly bound to the lamp. One supplier offers continuous chemical addition along with automatic wiping to assist in deposit removal. Regular cleaning is critical to maintaining optimum performance.

Lamp Control

Because UV disinfection uses more electrical power than traditional chlorine disinfection it is important to incorporate a control strategy into the system to help minimize the impact on energy costs. Two methods of control have been developed to stage the number of lamp banks in service. Flow pacing is perhaps the most common to date due to familiarity with its use on other processes. However, flow pacing alone does not account for changes in effluent quality. To prevent potential violations, this method is usually coupled with either a transmissivity or lamp intensity measurement. Flow pacing in combination with either of these should control the lamp banks as effectively and efficiently as possible.

PROJECT SUCCESS STORY

Elsinore Valley Municipal Water District

Description of Facilities: The Elsinore Valley Municipal Water District's regional Wastewater Reclamation Facility treats 4 mgd of domestic sewage. The liquid treatment at this facility consists of bar screening, extended aeration via oxidation ditch, secondary clarification, monomedia deep bed anthracite filtration, and chlorination.

Project Description: The facility's second chlorine contact basin was retrofitted with a UV system consisting of 10 UV banks. Each bank contains 15 modules with 8 lamps per module for a total of 1200 lamps oriented in an axial direction. The system was designed to deliver a UV output 26.7 watts/lamp after 100 hours of operation and an average UV dose greater than 140 mW/cm^2 at average daily and peak week flows. The control for the UV system is a PLC that monitors the system's functionality. The PLC interprets the data from both the turbidity monitoring units and flow sensors. With this information it then operates the UV system at peak efficiency by turning on and off channels, banks, and modules as needed.

Project Implementation

Predesign

- *Determine hydraulic loading.* System requirements need to be reviewed to ensure that the equipment capacity is not exceeded. UV disinfection systems are designed for peak flow rate. Therefore, the equipment that is installed must be able to hydraulically treat the range of flows expected at the treatment plant. Multiple banks of lamps need to be considered when designing the treatment system.

- *Evaluate the effluent water quality.* In the preliminary stages of the project, water samples of the treated wastewater need to be collected and analyzed for transmissivity, iron, hardness, color, temperature, soluble organics, suspended solids, and turbidity. Iron and hardness tend to coat the quartz sleeves that cover the lamps and may require frequent cleaning. Soluble organics, suspended solids, turbidity, and color all impede the transfer of UV light into the wastewater for disinfection. Temperature is a parameter that is frequently overlooked. In colder regions, the electrical output of the ballast is lower, so additional lamps may be required.

- *Determine the type of lamp required.* A pilot study should be conducted to determine whether a low- or medium-pressure system will be more feasible. The number of lamps, power consumption, maintenance workload, and effectiveness should be considered in the evaluation. The cost to improve effluent quality for use with UV disinfection should have been addressed in the preceding energy audit. This cost needs to be addressed when selecting the type of lamps.

- *Is the plant power supply capable of handling increased power draw?* The power draw to the treatment plant needs to be reviewed to ensure that ample power is available during start-up, normal operating conditions, and emergency conditions. This includes checking the harmonics of the electrical supply to ensure that the capacity is not exceeded. If the electrical harmonics are exceeded the electrical power to other parts of the treatment plant may be disrupted. An electrical interlock must be provided for each bank of lamps so that the bank can be taken out of service without impacting the operation of the other parts of the UV system.

- *Determine resources required for maintenance and cleaning.* Efficient and effective operation requires proper maintenance and frequent cleaning. In some plants, using existing staff to handle the increased workload can be difficult. With widespread cutbacks in funding, human resources can be a limiting factor that must be investigated.

- *Evaluate the location of the retrofit.* Review the proposed location of the UV system and evaluate the practicality of using an existing basin, if available. Inserting UV lamps into an existing channel will change the headloss through the channel. It is important to check the channel hydraulics to ensure that no adverse affects will result.

Design and Equipment Selection

- *Specify control requirements.* The electrical efficiency of a UV disinfection system greatly depends upon the control system. Various types of control systems are used ranging from no controls to transmissivity control.

Generally, these systems input information into either a local PLC or the overall plant SCADA system. From here, computer logic controls the number of lamps in service, the high/low power setting of the transformer, and even the cleaning on systems with automated wipers. Regardless of which is used, it is important to design the program to optimize the process by removing lamps or banks of lamps from service, based on flow and transmissivity.

- *Provide a backup disinfection system.* In order to avoid discharge violations that can occur when the system goes down, a backup disinfection system should be included in the project.
- *Investigate warranties and technical support.* Evaluate all manufacturer's warranties, technical support, and parts availability. The ability to meet a discharge requirement should not get hung up on a part that is not readily available or on a system that fails. In addition, a performance clause should be incorporated into the specifications to ensure that the system will cover the disinfection requirements imposed on the effluent stream.
- *Design with safety in mind.* Considering the necessity of frequent cleanings, it is important to eliminate all potential shock hazards in and around the cleaning area.

Installation Necessities

- *Ensure that channel hydraulics are correct.* UV channels must be inspected to ensure that they are straight and the basin floor is flat. Baffling should also be provided at the influent of the UV channels. Baffling will dissipate energy in the water allowing for smooth quiescent flow through the channels. Straight walls and a flat floor will help ensure that the entire flow receives an adequate dose of UV to inactivate the bacteria.
- *Provide for frequent maintenance and cleaning.* The UV lamps will need to be cleaned. Therefore, provisions must be added to make this work easy on treatment plant operators. For larger systems (over 5 to 10 mgd) this may include grouping the banks into a frame that can be raised and lowered using an overhead crane. The crane would be used to transfer the grouped banks from the treatment area to a container of cleaning solution and back to the treatment area. For smaller systems, (5 mgd), this may include: having the lamps enclosed in a building, racks for holding the lamps, the use of rubber mats on the floor and shelves, and availability of cleaning water. Electrical outlets must be capped so that water does not come in contact with the electrical connections.

Start-Up

- *Calibrate and debug the system.* Require the contractor to perform all final calibrations on any meters or probes used to monitor and control the system. Require that the system be operated at an expected range of flows and turbidity to demonstrate the proper operation of the control programming. Require the contractor to debug programming as needed to meet design specifications.
- *Provide adequate burn-in period.* UV lamps have to be conditioned before they are available for use. Typically called a burn-in period, it lasts for 100 hours. Adequate communication needs to occur between the contractor and the treatment plant operations staff to ensure an adequate burn-in period.

- *Conduct training as specified in the contract.* Specify an adequate amount of time for personnel training on the new system. Include training for operation, maintenance, and safety procedures on the lamps, chemical cleaning systems, and the control system and its programming.

Maintenance and Follow-Up

- *Establish a maintenance schedule.* Evaluate the performance of the lamps and develop a maintenance schedule that accounts for seasonal variations.
- *Collect data for system operation.* Typically, the following information must be collected:
    - Transmissivity.
    - Total suspended solids.
    - Turbidity.
    - Wattage output of lamps.
    - Hours of usage.
    - Replacement date.
    - Operation indication (on/off).
- *Develop trends from the data collected.* Operations staff can anticipate cleaning frequencies and respond quickly to changes in the system. This information also provides control data for the SCADA system so that it can respond to changes.
- *Review the collected data and adjust the programming.* Analyze the field data for trends or spikes that can be corrected with modification to the control programming. Include requirements in the contract to have the contractor review operations after the start-up period and make any requested or necessary programming changes.

References

1. Linden, Karl G.: *UV Acceptance*, Civil Engineering, pp 58-61, March 1998.

2. EPRI Community Environment Center: *UV Disinfection for Water and Wastewater Treatment*, Report C-105253, March 1996.

Additional Resources

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- Crites, Ron and Tchobanoglous, George: Small and Decentralized Wastewater Management Systems, McGraw-Hill, 1998, pp 859-876.

- Water Environment Research Foundation, Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance, Project 91-WWD-1, 1995.

- EPA, Municipal Wastewater Disinfection, EPA 625/1-86/021, October 1986.

UV Disinfection Retrofit Checklist

Predesign

- ❑ Determine the hydraulic loading.
- ❑ Determine the water quality of the effluent stream.
- ❑ Evaluate the effectiveness of low- and medium-pressure UV treatment on the effluent.
- ❑ Evaluate cost to improve effluent quality.
- ❑ Analyze the existing power supply for the increased power draw.
- ❑ Determine the increase in workload for maintenance of a new system.
- ❑ Evaluate the cost for training and staffing to operate a new process.
- ❑ Analyze the existing channel configuration and headloss with UV system.

Design and Equipment Selection

- ❑ Specify controlling the number of lamps in service with flow pacing and either transmissivity or lamp intensity monitoring.
- ❑ Specify high/low power feature when using medium-pressure systems.
- ❑ Develop a backup disinfection procedure.
- ❑ Eliminate electrical shock hazards from the cleaning area.

Installation Necessities

- ❑ Ensure that channel hydraulics are correct.
- ❑ Provide adequate space for cleaning lamps.

Start-Up

- ❑ Calibrate the system.
- ❑ Debug the program.
- ❑ Provide an adequate burn-in period.
- ❑ Conduct training on equipment, programming, and safety procedures.

Maintenance and Follow-Up

- ❑ Establish a maintenance schedule.
- ❑ Analyze the data collected for system improvements.
- ❑ Review the data with the manufacturer and have changes made to the programming as needed.
- ❑ Ensure that qualified vendors/consultants are available for questions.

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10

Alternatives for Managing Plant Loading

The previous sections have discussed opportunities to improve the electrical efficiency of existing equipment. Assuming the equipment is properly sized, the benefits of these retrofits are controlled by the daily flow rates for which the equipment was designed. That is, the equipment, like the plant, is sized for a designed biological and hydraulic loading and can save no more energy than that consumed by the most efficient unit. Although some types of processes consume less energy than others, it is seldom cost effective to demolish the present system to construct a new facility. Therefore, to achieve any further savings either the biological load would have to be reduced or the hydraulic load controlled.

Advanced Primary Treatment

APT can achieve an 80 percent removal efficiency for suspended solids and 50 percent for BOD_5.

The primary clarifiers are the first unit in a wastewater treatment facility that removes biosolids. There is very little energy consumed in this process yet it can significantly reduce the energy used in the rest of the facility. Biosolids from the primary clarifiers are pumped to a stabilization process, which is commonly an aerobic or anaerobic digester. The suspended solids and organic matter that pass through the primary clarifiers receive treatment in the secondary biological process. It is advantageous to maximize sludge removal in the primary clarifiers so that loading to the energy-intensive secondary process can be reduced.

Advanced primary treatment (APT) involves the addition of polymers or coagulants, such as alum or iron salts, to increase the removal of solids in the clarifiers. Conventional primary clarifiers can remove from 50 to 70 percent of the suspended solids and from 25 to 40 percent of the BOD_5.[1] Typically, APT can achieve an 80 percent removal efficiency for suspended solids and 50 percent for BOD_5.

APT provides additional benefits beyond lowering energy requirements in the secondary process. Increased solids removal in the primaries increases loading in the anaerobic digesters, which produces more gas for cogeneration. Thickening, dewatering, and hauling will improve due to the higher percentage of solids obtainable with primary sludge over secondary sludge.

Flow Equalization

Perhaps the greatest savings available in load-shifting strategies come from flow equalization. Flow equalization trims the peak off the typical diurnal flow pattern by the use of in-line or off-line storage basins. Equalizing flow creates a near-constant flow through the treatment process. This strategy not only reduces on-peak demand and energy consumption, but also simplifies operation of each unit process. Adjustment to each unit process for varied loading is greatly reduced, allowing their performance to be fine-tuned and maintained 24 hours per day.

When variations in primary effluent flows are dampened, facilities can achieve the following benefits:

- Lower peak electrical demand charges.
- Improved plant performance with a higher quality secondary effluent.
- Reduced shock loads.
- An increase in plant capacity.
- A reduction in the design size for a new plant or planned upgrade.
- More consistent filtration runs.
- Greatly reduced equipment runs for peak events.

Flow equalization is cheaper to implement in some facilities than others. Those with unused basins or available volume in basins currently used will have little expense in equalizing flow. Other facilities must conduct a feasibility study to analyze the construction of either an in-line or off-line equalization basin.

There are a few important points to consider when planning a flow equalization basin. First, determine whether an in-line or off-line basin is needed. With in-line basins, all flow passes through the basin, dampening both hydraulic and biological loads. However, these are often limited by available space. Off-line basins allow facilities to divert flow above a set rate. These dampen hydraulic loads but are not as effective on biological loads. When basins are planned as a means of reducing energy costs, their evaluation should include an estimate of savings from biological load reduction.

Secondly, facilities should use the basin to equalize primary effluent, not plant influent. This strategy will help prevent solids from settling out in the equalization basin and thus eliminate associated maintenance problems. Also, equalizing primary effluent avoids the aeration commonly required in basins that equalize plant influent.

Lastly, the basin should be designed so that it drains every day. This will reduce odors by fixing the detention time to prevent anaerobic conditions.

Incorporating an automatic flushing system that utilizes secondary effluent or non-potable (no. 3) water can help keep basins clean.

Project Implementation

Projects that alter the mass and hydraulic loadings create change throughout the entire treatment process. Proper analysis of the effects is important to the success of the retrofit. The following considerations can help facilities achieve the desired energy savings.

PROJECT SUCCESS STORY

Sanitation Districts of Orange County

Description of Facilities: Serving more than two million people in metropolitan Orange County, California, the County Sanitation Districts of Orange County provide primary and secondary treatment for approximately 250 mgd at two wastewater treatment plants. The District's system includes more than 800 miles of sewer pipelines, 22 pumping stations, 2 treatment plants and ocean disposal facilities.

Project Description: In June 1985, the Districts began using chemical addition of ferric chloride and anionic polymer at one of the two treatment plants for 6 to 12 hours per day to enhance the removal of total suspended solids and BOD. Chemical addition is now used at both treatment plants for 20 to 24 hours per day.

Results: The use of APT has:

- Increased digester gas production by 1000 kW.
- Reduced energy usage in secondary treatment by 1300 kW (40 mgd).
- Reduced other unit process electrical consumption by 1700 kW.
- Reduced capital expenditures for activated sludge by 40 mgd ($70 million).
- Reduced solids disposal by 37,330 wet tons per year, saving $1.12 million annually.

Capital costs for APT were minimal. Chemical costs average $2 million per year. The use of APT has eliminated the need to construct an additional 40 mgd of activated sludge (and other support) facilities, resulting in a capital cost savings estimated at $109 million.

PROJECT SUCCESS STORY

Irvine Ranch Water District

Description of Facilities: The Irvine Ranch Water District (IRWD) is a multi-task agency in south-central Orange County, California. The District is approximately 120 square miles and services a population of approximately 110,000. Reclaimed water for the District is produced at the Michelson Water Reclamation Plant (MWRP). The MWRP is a 15-mgd tertiary treatment plant with primary treatment, flow equalization, secondary treatment (activated sludge), secondary clarification, in-line chemical injection, tertiary treatment (dual-media filters), and chlorine disinfection.

Project Description To reduce on-peak charges during the summer months, the plant's operation department diverted primary effluent to the flow equalization basins from noon to 6 PM. Process air and the RAS rate were reduced and both energy and demand charges dropped significantly.

Results: During fiscal year 1994–1995, these energy-saving measures resulted in a total savings of $75,000 or 9.74% for the entire year. In addition to the energy cost savings, this energy conservation program has allowed for a greater awareness of the various treatment plant processes by the plant operations department, mechanical services department, electrical services department, and laboratory personnel.

Predesign

- *Check the feasibility analysis.* An energy study that suggested the use of APT or a flow equalization system most likely did not conduct an economic analysis to the level of detail necessary. Although energy audits conducted for other retrofits discussed in this manual are fairly complete, modifications to plant loading are not typically investigated to any great extent because of budget constraints. Check the level of analysis conducted in the energy study and, should it be lacking in detail, have additional analysis performed before proceeding with the project.

- *Verify Assumptions.* Verify that the assumptions and values used for the analysis are reasonable and current. It is possible that the retrofit will result in a new energy use profile and that a different rate schedule will be applicable. If the economic analysis does not use the new energy rates, the project feasibility might not appear favorable.

- *Verify that critical issues were addressed.* Verify that the system as a whole was addressed. Plants and their equipment are sized based on traditional flow patterns that will be altered either seasonally or permanently. Identify plant equipment that will need to be retrofit to take full advantage of the energy savings from the new loading. Ensure that the preliminary report has identified immediate and future compatibility problems with individual processes and has indicated ways for them to be resolved. Evaluate mixing and aeration needs for flow equalization.

- *Determine the increase in work load that the additional equipment will create.* Whereas flow equalization will not require much attention, the chemical feeders of an APT system will increase the operators' workload. If the plant is short-handed or otherwise constrained on budget, the operation of a more equipment may overwhelm staff.

- *Assess the effect on the master plan.* Both APT and flow equalization could increase a plant's treatment capacity, which affects the time and size of the next expansion. Additional savings could be found if the next expansion is delayed or reduced in size.

- *Assess the effect on the instrumentation and control system.* Verify that the existing control loops are properly modified for the new equipment and that the SCADA system is updated to include the new systems.

Design and Equipment Selection

- *Pilot Study.* Based on solids removal, an APT pilot study can evaluate the different types and dosages of chemicals. Size and selection of chemical feed units can then be determined with this information.

- *Equipment Selection.* When the optimum removal efficiency is determined by the pilot study, the feed system can be designed. Collecting a number of quotes from manufactures will create a competitive bid. Allow provisions to connect the feed equipment into a local PLC or the plant SCADA system.

- *Automate the flow equalization system.* Control the basin's operation to equalize flow either continuously or during peak electrical rate periods. The use of programmable logic to monitor the primary effluent flow rate and control the fill cycle is simple and extremely effective. Washdown can be simplified with automated flushing cycles that use plant utility water.

Installation

- *Involve operators and maintenance personnel in predesign and construction.* Operators and maintenance personnel should be involved early in the process so that they can provide input to ensure compatibility. If maintenance personnel are familiar with the equipment, repairs to the system can be made without unnecessary delays and costs for outside services.
- *Maintain field representation during construction.* An owner representative should be involved in the construction process to ensure that the design intent is being met.

Start-Up, Maintenance, and Follow-Up Essentials

- *Perform pre-start-up services.* Supervise all final adjustments, calibrate equipment, and check to make sure installation was completed adequately.
- *Conduct a performance test.* Require the contractor/vendor to conduct a start-up of all units with complete rechecks, calibrations, commissioning, and final adjustments to all equipment. Include a demonstration to ensure that the pumps or chemical feeders operate as specified under field conditions.
- *Perform scheduled recalibrations.* Recalibrate all probes and meters as required to avoid wasting chemicals or taking inaccurate readings.

References

1. G. Tchobanoglous and F.L. Burton, 1991. *Wastewater Engineering: Treatment. Disposal, Reuse*. Metcalf and Eddy, 3rd Edition.

Plant Loading Retrofit Checklist

Predesign

- ❑ Check feasibility study for completeness and perform additional analysis if needed.
- ❑ Verify that values used for the analysis are reasonable and up-to-date.
- ❑ Check the effects of the proposed project on entire treatment process.
- ❑ Identify other equipment in the plant that can be retrofit as a result of loading changes.
- ❑ Determine the increase in workload to operate new equipment.
- ❑ Determine the impact on the facility's Master Plan.
- ❑ Include the cost to modify existing control loops and SCADA programming.

Design and Equipment Selection

- ❑ Perform pilot study to select polymer and dosage.
- ❑ Include performance requirements in the specifications.
- ❑ Use pricing advantage of bid and include warranties and spare parts.
- ❑ Incorporate programmable logic control.

Installation

- ❑ Obtain operator's input for installation necessities.
- ❑ Maintain field representation during construction.

Start-Up, Maintenance, and Follow-Up Essentials

- ❑ Conduct pre-start-up services.
- ❑ Require the contractor/vendor to conduct a performance test.
- ❑ Develop and perform scheduled maintenance and recalibration of equipment.

An electronic version of this checklist is available on the *Energy-Water Connection* Web site at www.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

11

Lighting Retrofits

Recent advances in lighting technologies have provided wastewater facilities with a host of options for upgrading lighting systems in offices, laboratories, storage spaces/warehouses, operations and maintenance buildings, and outdoors. A good selection of lower-wattage lamps and sophisticated controls are available for a wide variety of applications.

Benefits of Lighting Retrofits

Lighting retrofits can significantly improve energy efficiency and lighting quality. Benefits can include the following:

- *Reducing energy costs.* Lighting retrofits reduce energy consumption by reducing the electrical demand from lighting fixtures when they are operated, and reducing consumption by turning lights off (or dimming them) when they are not needed.
- *Maintaining or improving lighting quality.* Lighting retrofits can significantly improve the quality of lighting in your plant. These measures can incorporate improvements that control glare, provide greater uniformity of illumination, and enhance color rendering. As a result, employee productivity may be enhanced.
- *Reducing maintenance costs.* A quality lighting retrofit will replace lighting system components with products of higher quality and performance, include new energy-efficient fixtures and subsystems, and establish cost-effective lighting maintenance strategies.
- *Reducing heat output.* Lighting retrofits may reduce cooling costs and possibly allow future equipment to be down-sized, reducing capital costs.

Conducting the Retrofit

This section provides a basic primer on lighting components and then describes the following retrofit measures:

- Fluorescent Lighting Upgrades
- Fixture Upgrades
- Incandescent Lighting Upgrades
- High Intensity Discharge Lighting (HID) Upgrades
- Occupancy Sensor Installation
- Scheduling Controls Installation

Lighting Components

Lamps

Industrial facilities such as wastewater plants use several different light sources. Each lamp type has particular advantages; selecting the appropriate source depends on installation requirements, life-cycle cost, color qualities, dimming capability, and the effect wanted. Three types of lamps are commonly used: incandescent, fluorescent, and HID.

HID lamp technology includes four types of lamps: mercury vapor, metal halide, high-pressure sodium, and low-pressure sodium. Table 11-1 compares several characteristics of lamp types.[1,2]

Table 11-1. Comparison of Lamp Characteristics

	Standard Incandescent	Tungsten Halogen	Fluorescent	Compact Fluorescent	Mercury Vapor	Metal Halide	High-Pressure Sodium	Low-Pressure Sodium
Wattage	3–1,500	10–1,500	4–215	5–40	40–1,250	32–2,000	35–1,000	18–180
System Efficacy (lm/W)	6–24	18–33	50–100	50–80	25–50	40–100	40–140	120–175
Lamp Life (hrs)	750–2,000	2,000–4,000	7,500–24,000	10,000–20,000	24,000+	6,000–20,000	16,000–40,000	12,000–18,000
Color Rendering Index	95+	95+	62–92	82–86	22–52	65–85	21–80+	0–18
Start to Full Brightness	instant	instant	0–5 sec.	0–1 min.	2–5 min.	4–6 min.	2–5 min.	10–15 min.
Restrike Time	instant	instant	instant	instant	3–10 min.	10–20 min.	1 min.	instant

Ballasts

All discharge lamps (fluorescent and HID) require an auxiliary piece of equipment called a ballast. Ballasts have three main functions: to provide a higher voltage for starting lamps, to match line voltage to the operating voltage of the lamp, and to limit current to the lamp to prevent potential damage when the lamp's impedance decreases after the arc is struck.

Ballasts are an integral component of the lighting system and have a direct impact on light output. The ballast factor for a specific lamp-ballast combination is the percentage of rated lamp output that will be produced by that combination. General-purpose ballasts have a ballast factor that is less than one; special ballasts may have a ballast factor greater than one. There are two primary types of fluorescent ballasts: magnetic and electronic. "Hybrid" ballasts are magnetic ballasts which contain an electronic heater-cutout circuit.

Electronic ballasts improve efficacy by converting the standard 60-Hz input frequency to a higher frequency, usually 25–40 kHz. Lamps operating at these higher frequencies produce about the same amount of light, while consuming 12–25 percent less power than magnetic ballasts. Other advantages of electronic ballasts include less audible noise, less weight, virtually no lamp flicker, and dimming capabilities (with specific ballast models). Ballast designs are available in standard or dimmable T-12 and T-8 versions, as well as for compact fluorescents.

Light Fixtures

A light fixture (or *luminaire*) is a unit consisting of the following components: lamps; lamp sockets; ballasts; reflective material; shielding materials such as lenses, refractors, or louvers; and the housing.

The main function of the fixture is to direct light using reflective and shielding materials. Many lighting retrofit projects replace one or more of these components to improve fixture efficiency (defined as the percentage of lamp lumens, or total lamp output, that actually exit the fixture). Alternatively, you may consider replacing the entire fixture with one that is designed to efficiently provide the appropriate quantity and quality of illumination. Examples of fixture types include:

- General illumination (direct) fixtures such as 2x4, 2x2, and 1x4 fluorescent troffers.
- Indirect lighting, such as pendant-mounted fixtures.
- Spot or accent lighting, such as track lights in retail displays.
- Task lighting, such as under-shelf cubicle fixtures.
- Area (indoors or outdoor) and flood lighting, such as parking lot lights and wall-mounted floodlights.

One of the primary functions of a fixture is to direct light (using reflectors, lenses and louvers) to where it is needed.

Lighting Retrofit Technologies

Here is a brief description of currently-available lighting retrofit technologies, including their common applications and limitations. Many product variations exist within each technology described. Contact a lighting consultant, contractor, or manufacturer for application assistance on specific products.

Fluorescent Lighting Upgrades

Recent advances in fluorescent lighting technology have created new products. Fluorescent lamps are designated by factors of eighths of an inch. For example, a T-12 lamp is $^{12}/_{8}$ or 1 $^{1}/_{2}$ inches in diameter and a T-8 lamp is $^{8}/_{8}$ or 1 inch in diameter. The following is a brief description of parts that improve the efficiency of light fixtures.

Energy-saver fluorescent lamps. The "energy saver" fluorescent lamp is essentially a standard 4-foot, 40-watt fluorescent lamp that is filled with an argon-krypton gas mixture, rather than just the argon gas contained in a standard fluorescent lamp. This argon-krypton mixture causes the lamp to draw only 34 watts, with a reduced light output. Similar reduced-wattage versions are available for 8-foot lamps.

Energy-saver lamps may be used to replace standard T-12 lamps in spaces that are currently over-illuminated. This retrofit produces about 19 percent in energy savings with a 19 percent reduction in light output.[1,2] No ballast upgrades are required when converting to energy-saver lamps.

T-8 lamp-ballast upgrade. The T-8 lamp-ballast system has the highest efficacy of any fluorescent system. T-8 lamps have the same medium bi-pin bases as T-12 lamps, allowing them to fit into the same sockets. However, T-8 lamps operate on a reduced current (265 mA) and must be operated using a ballast that is designed for T-8 lamp operation. When using T-8 lamps, specify lamps with a color rendering index (CRI) of at least 75 to yield maximum efficacy and improved color rendering.

Full-output electronic ballasts. Full-output electronic ballasts are high-frequency versions of conventional magnetic core-and-coil ballasts. Electronic ballasts operate fluorescent lamps more efficiently because they drive them at frequencies greater than 20 kHz. The resulting increase in lamp efficacy, combined with reduced ballast losses, boosts system efficacy by up to 30 percent.[1,2] In nearly every fluorescent lighting system, full-output electronic ballasts can replace magnetic ballasts, providing similar light output with significant reductions in energy consumption.

Other advantages include reduced weight, less (humming) noise, virtually no flicker, and the capability to simultaneously operate four lamps at a time (most magnetic ballasts are designed to operate only two lamps at a time).

If lighting fixtures in a particular space are only equipped with two lamps, take advantage of this more-efficient lamp-ballast combination by "tandem wiring" pairs of 2-lamp systems to share 4-lamp ballasts.

Partial-output electronic ballasts. Partial-output, also known as *low-wattage* electronic ballasts, operate fluorescent lamps at the same efficacy as other electronic ballasts, but with specified reductions in both light output and energy consumption.

Hybrid magnetic ballasts. Hybrid magnetic ballasts, also known as *cathode cutout ballasts,* cut the voltage to the cathodes in rapid start fluorescent lamps once the lamps are operating. They are suitable for all 2-lamp magnetic ballast applications for 4-foot rapid start fluorescent lamps. They are about four dollars less expensive and nearly as efficient as 2-lamp electronic ballasts. However, greater energy and material cost savings can be realized using electronic ballasts, where applicable.

In applications where electromagnetic interference (EMI) from electronic ballasts is a potential problem (as in the immediate vicinity of very sensitive electronic equipment), hybrid magnetic ballasts should be considered.

Hybrid ballasts are manufactured as either full-output or partial-output devices. Partial-output hybrid ballasts consume about the same wattage as electronic ballasts, but produce about 10 percent less light output.

"Energy-efficient" magnetic ballasts. These ballasts are premium versions of the older standard magnetic core-and-coil ballasts. As of April 1992, the Federal Appliance Standard prohibits the manufacture of standard magnetic

ballasts, making energy-efficient magnetic ballasts the new standard for magnetic ballast production. These are now the least energy-efficient ballasts that you can buy to operate full-size fluorescent lighting systems.

Fixture Upgrades

Delamping. Delamping is simply the removal of one or more lamps from a fixture. For safety reasons, delamping is uncommon in a treatment facility in areas other than the administration offices. Task-oriented delamping works well in offices to place more light directly on the work area and less light in circulation areas. Wastewater facilities with larger office areas can benefit from uniform delamping. It is important to relocate the remaining lamps so that they are centered on each half of the fixture. In addition, higher output lamps, reflectors, lens upgrades, fixture cleaning, and task lighting will minimize the reduction of light output. An energy savings of over 60 percent can be achieved by removing two U-lamps in a 2x2 fixture and installing two or three UL-classified conversion 2-foot, 17-watt T-8 lamps, electronic ballasts, and specular reflectors.[2]

Lens/louver upgrades. Fixture efficiency can be significantly improved by replacing inefficient or deteriorated shielding materials. Clear acrylic lenses provide maximum efficiency, and new "low-glare" clear lenses provide high efficiency and good glare control. Deep-cell parabolic louvers also provide a good combination of efficiency and glare control.

New efficient fixtures. Instead of upgrading individual fixture components, consider the labor savings and quality improvements that may be achieved by replacing existing fixtures with completely new fixtures that feature high-efficiency components. For example, T-8 lamps with electronic ballasts, deep-cell parabolic louvers, and occupancy-sensor controls.

Conditions that enhance the cost-effectiveness of new fixtures include:

- Where multiple-fixture component replacements are considered (new lamps, ballasts, reflectors, lenses, etc.).
- Where deep-cell parabolic louvers or indirect lighting systems are desired for combined efficiency and glare control.
- Where the space will be remodeled or the fixtures locations will be changed. New fixtures should be considered in offices where computers are used.

Deep cell parabolic fixtures. Deep-cell parabolic fixtures provide large-width louver cells (4–7 inches) to allow the light to efficiently exit the fixtures while providing glare shielding for high visual comfort. The vertical surfaces of these louvers are parabolic in shape, thereby reducing light loss resulting from inter-reflection within the louver. Deep-cell parabolic fixtures are generally preferred where computers are in use.

Indirect fixtures. Indirect fixtures distribute at least 90 percent of the emitted light upwards to reflect off the ceiling and upper walls, providing uniform, diffuse lighting on ceilings, walls, and tasks. For safety reasons, indirect lighting is seldom used in the working areas of treatment plants. However, since the light sources are completely shielded from the view of the occupants, indirect systems provide relatively high visual comfort and work well in partitioned office areas.

Task lighting with delamping. Significant energy savings and lighting quality improvements can be achieved by providing light sources at specific task locations while reducing ambient (overhead) lighting. The 50 footcandles that are normally needed for typical reading and writing tasks can be achieved with a task light that provides at least 25–30 footcandles and an ambient lighting system that provides only about 20–30 footcandles. Compact fluorescent task lighting with delamping increases visual comfort, saves energy, and provides users with greater control over their workstation illuminance.

Task/ambient lighting designs are best suited for office environments with significant computer use and/or where modular furniture can incorporate task lighting under shelves. (In other cases, desk lamps may be used to provide task illumination.) Non-office task/ambient applications in wastewater plants include laboratory spaces, machine- and equipment-assembly areas, and process/inspection areas.

Incandescent Lighting Upgrades

Wherever feasible, alternatives to the use of low-efficacy incandescent lamps should be pursued. With recent advances in compact fluorescent and halogen lamps, many options are now available:

Compact fluorescent lamp retrofits. Compact fluorescent lamps are an energy-efficient, long-lasting substitute for the incandescent lamp. They are available in a wide variety of configurations beyond the most common twin-tube, quad-tube, and triple-twin-tube configurations. Compact fluorescents can be purchased as self-ballasted units or as discrete lamps and ballasts. Several retrofit adapters are available for convenient retrofit in existing incandescent sockets. Many compact fluorescent products are now manufactured with electronic ballasts which provide 20 percent higher efficacies as well as instant starting, reduced lamp flicker, quiet operation, smaller size, and lighter weight. Compact fluorescents may be used in a variety of incandescent applications including downlights, surface lights, pendant fixtures, task lights, compact troffers, sconces, exit lights, step lights, and flood lights.

Compact halogen lamp retrofits. Compact halogen lamps consist of a small tungsten-halogen capsule lamp within a standard lamp shape. These lamps are adapted for use as direct replacements for standard incandescent lamps. Halogen lamps are more efficient, produce a whiter light, and last longer than conventional incandescent lamps. As a general rule, compact halogen lamps should be considered for replacing incandescents wherever the more efficient compact fluorescent would not be a beneficial choice. Compact halogen lamps can be dimmed, their performance is independent of temperature and orientation, they project light efficiently over long distances, and they present no power quality or compatibility concerns. Good applications include high-ceilinged downlighting and instant-on floodlighting. The use of specially-designed reflectors or an optional infrared (IR) coating applied to the halogen capsule can increase the efficacy of this light source even more.

Exit sign upgrades. All emergency exit signs should illuminate 24 hours per day and be able to continue operation in the event of power failure. Exit sign upgrades offer the potential for huge reductions in energy and maintenance costs. Of the numerous light sources now available for replacing the up to 40 watts of incandescent power consumption in exit signs, the following three are the most viable: light emitting diode (LED), low-wattage incandescent assembly, and compact fluorescent. Of the exit sign retrofit options, LED sources are the most energy efficient—only consuming 2–5 watts per exit sign kit—and have the longest life. Whatever connection methods are used, installation is relatively easy, usually taking fifteen minutes or less per sign.

High Intensity Discharge Lighting Upgrades

The primary method of improving the energy efficiency of HID systems is to replace the light source with a more efficacious system. Some of the other viable retrofit options include reduced-wattage lamps and ballasts, and bi-level switching.

Conversion to a high-efficiency HID system. Existing high-bay or outdoor lighting systems that use incandescent, mercury vapor, or (in some cases) fluorescent lamps may be replaced with metal halide, high pressure sodium, or low pressure sodium systems. These retrofits normally include a complete fixture replacement, including the lamp, ballast, and optical assembly.

The most cost-effective retrofits involve replacing less-efficient sources such as incandescent or high-output and very-high-output [HO/VHO] fluorescent systems. This may involve a one-for-one fixture replacement or a new layout of fixtures to take advantage of the inherent light distribution characteristics of HID fixtures.

Reduced-wattage HID systems. Reduced-wattage HID metal halide and high pressure sodium systems are available that reduce energy consumption by up to 18 percent with a corresponding reduction in light output. These retrofit technologies are available as either reduced-wattage retrofit lamps or lamp/ballast system retrofits.

Bi-level switched HID fixtures. Capacitive switching (usually called *bi-level* or *hi/lo*) HID fixtures are designed to provide either full light output or partial light output based on inputs from occupancy sensors, manual switches, or scheduling systems. This method of dimming HID fixtures can be installed as a retrofit to existing fixtures, or more commonly, as a complete fixture replacement. The most common applications of bi-level switching are occupancy-sensed dimming in parking lots and storage/warehouse aisles. General purpose transmitters can be used with other control devices such as time clocks and photosensors to control the bi-level switched fixture system.

Occupancy Sensor Installation

Reducing the energy consumed by lamps and fixtures represents only half the potential for maximizing energy savings. Reducing operating hours by shutting lights off with automatic controls represents the other half. Occupancy sensors are cost-effective devices that can ensure that the lights are energized only when occupants are present. For safety reasons, some buildings in a plant should not use these controls. For example, in buildings where equipment could shield an employee from the control's sensor, a person could be left in the dark, surrounded by potentially dangerous equipment. Similarly, using controls on HID lamps can be inconvenient in frequently occupied rooms, because of their long strike times. If HID lamps are inadvertently tripped off by motion controls, they can take a while to restrike.

Less-frequented rooms can benefit from occupancy sensors. Typical energy savings potential with occupancy sensors is as follows:

Energy Application	Potential Savings*
Offices (private)	25–50%
Office (open spaces)	20–25%
Rest Rooms	30–75%
Corridors	30–40%
Storage Areas	45–65%
Meeting Rooms	45–65%
Conference Rooms	45–65%
Warehouses	50–75%

*Note: Figures listed represent maximum energy savings potential under optimum circumstances. Figures are based on manufacturer estimates. Actual savings may vary.

Occupancy sensors may be installed to provide on/off control of incandescent or fluorescent loads as well as bi-level control of capacitive-switched HID fixtures.

Most occupancy sensors have adjustable settings for both sensitivity and time delay. The sensitivity setting allows the user to fine-tune the sensor for the activities that occur in the space to ensure that normal motion is detected without triggering responses to extraneous signals. The time delay setting can be adjusted to determine when fixtures will be turned off when no motion is detected. The time delay prevents the fixtures from switching off during intervals when people are in the room, but are moving too little or too slowly to be detected by the sensor.

Some occupancy sensors provide daylight switching with their occupancy switching control. A trial installation is recommended to assess user acceptance of this technology.

Application guidelines. Occupancy sensors are available in both ceiling-mounted and wall-mounted versions, utilizing either infrared or ultrasonic sensing technologies. More recently, dual-technology (or *hybrid*) sensors have become available to prevent inadvertently switching lights off when the room is occupied. Typically, only the infrared or the ultrasonic portion of the unit sensor must be triggered to turn lights on, but non-occupancy indication (that is, the absence of triggering) from both sensors is required to turn lights off.

Wall-mounted sensors. Common applications of wall-mounted sensors include separately-switched areas such as conference rooms, classrooms, individual offices, and storage rooms. Because these devices are mounted in existing light switch locations, the coverage pattern provided by the sensor should be checked to ensure that it will adequately detect motion throughout the room. In addition, verify that the type of motion in the space will be detected, given the sensor type and location. In addition to the "automatic-on/automatic-off" function, other control options include:

- *Manual-on/automatic-off:* These sensors must be switched on manually to turn the lights on; the unit automatically turns the lights off when motion is no longer detected in the room.
- *Two-level:* For retrofit of dual switching systems (with two switches providing two levels of light), the user has the option to manually select either a "half-on" or "full-on" setting on the occupancy sensor.
- *Daylight switching:* These sensors can be calibrated to turn off the lights when ambient light levels reach a preset target. Some sensors will not allow the lights to turn off when occupants are present due to daylight contribution.

Ceiling-mounted sensors. Ceiling-mounted sensors should be used in areas where wall-mounted switches would be inadequate, such as corridors, rest rooms, open office areas, warehouse aisles, and spaces where objects obstruct the coverage of a wall-mounted sensor. These sensors are usually wired to a separate control module and one or more relays that perform the actual switching function in the ceiling space/plenum. Multiple sensors and lighting circuits can be controlled by one control module, but manufacturers specify a maximum distance between the sensors and the control module for reliable operation.

Motion-sensing technologies. The two most common motion-sensing technologies used in occupancy sensors are passive infrared and ultrasonic.

- *Passive infrared (PIR) sensors.* PIR sensors respond to motion between horizontal and vertical cones of vision defined by the faceted lens surrounding the sensor. As an occupant moves a hand, arm, or torso from one cone of vision to another, a positive "occupancy" signal is generated and sent to the controller. Most PIR sensors are sensitive to hand movement up to a distance of 10 feet, arm and upper torso movement up to 20 feet, and full-body motion up to about 40 feet. Note that these types of sensors require an unobstructed view of the motion and are much more sensitive to motion occurring perpendicular to the line-of-sight to the sensor. PIR sensors will not perform properly in spaces where furniture, partitions, or other objects are between the sensor and the occupant.
- *Ultrasonic sensors.* Ultrasonic sensors emit and receive high-frequency sound waves in the range of 25–40 kHz, well above the range of human hearing. These waves reflect off objects and room surfaces. If there is motion in the space, the sensor detects the resulting change in the frequency of the reflected wave and generates a positive occupancy signal to turn the lights on. Ultrasonic sensors do not require direct line-of-sight to detect motion, although the space must be enclosed and must consist of hard surfaces for the reflected waves to eventually return to the receiver. They

are also much more sensitive to movement directly toward or away from the sensor, compared to lateral movements.

Scheduling Controls Installation

In addition to occupancy sensors, scheduling controls are designed to help eliminate unnecessary use of lighting.

Time-switched systems. Time-switched systems ensure that lighting is turned off or dimmed according to an established schedule. Examples are as follows:

Wallbox electronic timer switches. Installed in place of manual switches to allow an occupant to pre-select a period of operation.

Time clocks. Used to control lighting systems with predictable operating periods, such as security lighting and corridors.

Programmable "sweep" systems. These systems establish a programmed schedule for sequentially turning off lights throughout a floor or an entire building. Components typically include a central processor, remote relays for the lighting zones controlled, and override switches.

Daylight switching systems. Photocells or scheduling systems may be used to automatically turn off lighting systems when sufficient daylight is available. All outdoor lighting should be controlled using a daylight switching system, typically for "dusk-to-dawn" operation. For applications where outdoor lighting is not needed for dusk-to-dawn illumination, a timed switching system may be wired in series with the photosensor to switch off the circuit before dawn.

As an alternative to photosensors, consider installing a microprocessor-based timed switching system for controlling outdoor lighting. Systems are available that predict seasonal dusk and dawn switching times and automatically switch the lighting according to this schedule. Such systems must have battery backup and memory in order to ensure that the "solar schedule" will remain properly programmed in the event of a power failure.

Lighting Waste Disposal

Upgrading a lighting system will likely involve the removal and disposal of lamps and ballasts. Some of this waste may be hazardous, and you must manage it accordingly. (Note that the following information does not constitute legal advisement; wastewater facilities management should check with local, state, and regional authorities for the most up-to-date information.)

Disposal of PCB-Containing Ballasts

The primary concern regarding the disposal of used fluorescent ballasts is the health risk associated with polychlorinated biphenyls (PCBs). Human exposure to these possible carcinogens can cause skin, liver, and reproductive disorders. Fluorescent and HID ballasts contain a small capacitor that may contain high concentrations of PCBs (greater than 90 percent pure PCBs or 900,000 ppm). These chemical compounds were widely used as insulators in electrical equipment such as capacitors, switches, and voltage regulators through the late 1970s.

The Toxic Substances Control Act (TSCA) enacted in 1976 banned the production of PCBs in the United States. The specific regulations governing the use and disposal of PCBs are found in Volume 40 Code of Federal Regulations (CFR) Part 761. Additionally, the notification and liability provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) are applicable.

The following guidelines may be used to identify ballasts that contain PCBs:

- All ballasts manufactured through 1979 contain PCBs.
- Ballasts manufactured after 1979 that do not contain PCBs are labeled: "No PCBs."
- If a ballast is not labeled "No PCBs," assume it contains PCBs.

The details of determining the type and condition of used ballasts; appropriate methods to store, pack, ship and dispose of used ballasts; and costs associated with the various methods of disposal are beyond the scope of this manual. Before implementing a lighting retrofit project, wastewater facility managers should get advice on ballast disposal from local, state, and regional authorities. At a minimum, the following steps should be taken:

- Investigate and follow state and local requirements for handling and disposing of ballasts.
- Identify ballasts that contain PCBs and ballasts that are leaking PCBs.
- Remove, handle, and dispose of leaking PCB-containing ballasts by high-temperature incineration.
- It is recommended that non-leaking PCB-containing ballasts be disposed of in an environmentally-responsible manner, such as by high-temperature incineration, recycling, or chemical or hazardous waste landfill.
- Maintain permanent records of PCB-containing ballast disposal.

Disposal of Mercury-Containing Lamps

Fluorescent and HID lamps contain a small quantity of mercury that can be harmful to the environment and to human health when improperly managed. To prevent these toxic materials from contaminating the environment, dispose of used lamps responsibly.

Mercury is regulated under Federal Regulations established by the Resource Conservation and Recovery Act (RCRA), which is administered by the U.S. Environmental Protection Agency. Additional applicable Federal Regulations include CERCLA. The details of determining applicable exemptions; whether the used lamps are defined under RCRA as hazardous waste; and the appropriate methods to store, pack, ship, and dispose of used lamps is beyond the scope of this manual. Prior to implementing a lighting retrofit project, plant managers should get advice on lamp disposal from local, state and regional authorities. At a minimum, the following steps should be taken:

- Investigate and follow state and local requirements for handling and disposing of lamps.
- If you have not tested your mercury-containing lamp wastes to show that they are not hazardous, then assume they are hazardous and dispose of them as hazardous waste.
- Mercury-containing lamps that test hazardous must be handled in compliance with hazardous waste regulations.
- Maintain permanent records of mercury-containing lamps that are disposed of as hazardous waste.

Information Resources for Lighting Waste Disposal

For project-specific assistance, you may contact the following (as of 1997):

- U.S. Environmental Protection Agency Regional Office, Toxic Substances Control Act (TSCA) Assistance Information Hotline: (202) 554-1404
- CERCLA National Response Center (NRC) Hotline: (800) 424-8802
- EPA-approved disposal locations, including PCB incinerators and commercially-permitted hazardous waste landfills.

Lighting Maintenance

Proper lighting system maintenance is essential to high-quality efficient lighting. Systematic lighting management methods and services from lighting specialists can help organize the process and assure continued high performance of any lighting system.

Lighting maintenance is more than simply replacing lamps and ballasts when they fail. Plant managers must manage their lighting resources (i.e., fixtures, lamp/ballast inventory, labor, and energy) to sustain the quality of the lighting system.

The light output of a luminaire decreases with age and use, yet the energy input remains unchanged. Because the human eye is extremely adaptive to gradually changing lighting conditions, most occupants do not notice the gradual decline of light levels. Eventually, however, the reduction will affect the appearance of the space and the productivity and safety of the occupants.

Maintenance Planning

Many maintenance managers are hesitant to replace lamps that are still operating. But group relamping and cleaning can be less expensive than sporadic spot maintenance. Through strategic planning and performance management of the overall lighting system, costs can be reduced and lighting quality improved.

Group relamping is analogous to changing the spark plugs in your car. All of the spark plugs are changed at the same maintenance interval. This saves time and money and improves the overall efficiency of your car. As the spark plugs age, gas mileage of the car declines. Similarly with lighting, the efficiency and output of the system will decrease as the lamps age. This change could decrease worker productivity or the safety of personnel. The most efficient maintenance method is to group-replace your lamps, just as you would group-replace the spark plugs in your car. Specific advantages of group relamping and cleaning include:

- Minimizes potential disruption of plant operations due to lack of illumination.
- Saves money, time, and energy.
- Improves overall system efficiency.
- Reduces maintenance time and costs.
- Efficiently utilizes maintenance personnel.
- Reduces lamp and ballast inventory.
- Reduces material costs through bulk purchasing practices.
- Provides higher maintained light levels.
- Prevent unnecessary ballast degradation caused by ballasts trying to start expired lamps.
- Technician does not have to replace lamps individually.

Getting Help

As the demand for planned lighting maintenance has increased, so have the services offered by the lighting industry. The following are some resources available to help analyze, plan, and implement efficient lighting maintenance.

Lamp manufacturers. Although strategic lighting management can save energy and labor costs, group maintenance will usually require the use of more lamps. As a result, lamp manufacturers have an interest in providing assistance in analyzing lighting management strategies. Most of this assistance is valuable and reliable and offered free (or at low cost). Contact your lamp supplier or manufacturer for information.

Lighting management companies. Lighting management companies are maintenance or electrical contractors that specialize in lighting installation, upgrade, management, and maintenance. Many offer a free or low-cost service to identify optimum lighting maintenance programs. Some may offer consulting services to help develop in-house lighting management programs, but most are interested in providing upgrade installation and maintenance contract services.

Project Implementation

Successful implementation of a lighting retrofit project will require wastewater plant staff to carefully consider and plan all key aspects of the project. These considerations, summarized in a checklist at the end of this section, are as follows:

Predesign

- *Assess required level of expertise.* Many lighting projects, such as compact fluorescent retrofits, can be easily performed by plant staff. Other projects, such as modification or replacement of lighting fixtures, may require a qualified lighting designer.
- *Confirm assumptions and benefits.* Verify that the assumptions used for calculating the project economics were reasonable. Are estimates of the operating hours of lighting systems in different areas of the plant reasonable? Were the correct electric rates and demand charges used? Was a reliable method of cost estimating used? Were disposal costs included for old lamps and ballasts? Note that future utility deregulation could change the cost of electrical energy.
- *Determine the requirements for lighting retrofits.* Target illumination levels for proposed retrofit spaces (use IES recommendations, or specific user requirements) need to be specified to insure adequate lighting in critical areas. Many hardware replacements, though more efficient, will reduce the amount of lighting. In some rooms, specifically those with complex machinery, lighting levels should be established with employee safety in mind. Lighting quality should be maintained or improved. Low-glare fixtures should be used in areas with video display terminals.
- *Coordinate construction with operations.* Construction phasing/sequencing should be coordinated with the plant operations schedule.
- *Include maintenance needs in the design.* Modifications and additions should promote ease of maintenance.
- *Determine where lighting controls are applicable.* Not all rooms need to have lighting controls. If worker safety can be compromised when lights automatically turn off or if long strike times are inconvenient, lighting controls might not be appropriate. Where controls are appropriate, specify systems that will properly interface with existing plant controls, instrumentation, and operational requirements.
- *Determine appropriate lighting types.* Some rooms in a treatment plant are either infrequently occupied or occupied for only a short time. This makes the long strike times of HID lighting inconvenient. In this situation, fluorescent lighting with its lower efficiency can actually use less energy because HID lighting, if used, will be left on where fluorescent lighting is convenient to turn off.
- *Avoid harmonic distortion near sensitive equipment.* Fluorescent ballasts produce some degree of harmonic distortion. Without proper precautions this can interfere with instrumentation.

Design and Equipment Selection

Design and equipment considerations are listed by category of retrofit type.

Fluorescent Lighting Upgrades

- *Select the proper lamps and ballasts for each application.* When replacing fixture components, use compatible equipment. For example, T-8 lamps are designed to work with T-8 ballasts and high-output T-12 lamps are designed with high-output ballasts.

- *T-8 lamp-ballast upgrades.* Electronic T-8 ballasts should be used for maximum efficiency. Although T-8 lamps are classified as rapid-start lamps, electronic ballasts can be designed to start these lamps in either the rapid-start or instant-start mode. There is a trade-off to consider when choosing between rapid-start and instant-start T-8 electronic ballasts: T-8 lamps operating on instant-start ballasts will produce about 6 percent more lumens per watt (more efficient), but may reduce lamp life. The amount of lamp life reduction depends on how frequently the system is switched on and off: At 3 hours per start, the lamp life reduction is 25 percent, but at 12 hours per start, the reduction is negligible. In most cases, the financial advantage of using the more efficient instant-start ballasts more than offsets the costs associated with reduced lamp life. However, when occupancy sensors will be used and frequent switching is expected, consider using rapid-start ballasts.

- *Energy-saver lamps.* Although the unit wattage is reduced, the light output from this "energy saver" T-12 fluorescent lamp is also less than a standard lamp. Further, the ballast factor is lowered from 94 to 87 when using magnetic ballasts, resulting in a cumulative 19 percent reduction in light output. Verify that target light levels are achieved with this adjustment. These lamps cannot be dimmed as easily as standard 40-watt T-12 lamps and are very sensitive to temperature. In fact the minimum starting temperature is 60°F.

- *Check compatibility with existing equipment.* On rare occasions, certain high-frequency ballasts may be incompatible with existing equipment. For example, some older occupancy sensor relays may fail when installed on the same circuit as a new electronic ballast. In addition, electronic ballasts may impair the operation of electronic security systems.

- *Determine wire length for tandem-wired lamps.* When wiring pairs of 2 lamp fixtures to one ballast, check with the manufacturer to determine the maximum length of the "whip" between lamp and ballast that will still provide reliable operation.

- *Implementation of task lighting.* In some cases, the use of incandescent task lights may add more electrical demand than can be eliminated from the ambient lighting system. Consider using compact fluorescent technologies, which are a very efficient source of task lighting. To reduce reflected glare, consider specifying compact fluorescent task lights that allow users to position the light to the side of the task. The practicability and cost of rewiring should be addressed in the qualification of this retrofit.

Fixtures Upgrades

- *Delamping.* Specify that target light levels are to be maintained with this adjustment. Require that the remaining lamps are relocated to prevent uneven lighting and that the series-wired ballasts previously used be removed from the fixture. Specify that unused sockets are to be removed to prevent the reuse of those sockets in the future. Delamping may not be feasible in series-wired 2-lamp fixtures (removal of one lamp extinguishes the other lamp). The appropriate energy-efficient solution may be to keep both lamps and operate them with a partial-output electronic ballast.

- *Reflector retrofits.* Light levels are typically reduced by 30–45 percent when installing reflectors and using 50 percent of the original lamps in 2x4 troffers. Specify only UL-classified reflectors and accessories that include installation instructions for your specific fixture's make and model. Check the design for accessibility to the ballast compartment. Differences between manufacturers' reflector designs and materials can cause wide variations in reflector performance. Consider review of independently-measured performance data[2].

- *Lens/louver upgrades.* Retrofits using smaller-cell parabolic louvers (2 inches or smaller) provide high visual comfort but significantly reduce efficiency. Verify that the photometrics demonstrate that target light levels are met. If sufficient plenum space is available above the ceiling grid, deep-cell parabolic louver upgrades can be installed in many kinds of existing fluorescent fixtures. Alternatively, consider installing new fixtures (with deep-cell parabolic louvers) or retrofit with low-glare clear lenses.

- *New energy-efficient fixtures.* Before selecting new fixtures, confirm with a lighting systems designer that the correct number and spacing of the fixtures based on published photometric data and the target illumination level. The practicability and cost of rewiring should be addressed in the qualification of this retrofit.

- *Deep-cell parabolic fixtures.* Avoid shadows that can appear in the upper sections of walls, creating a "cave effect."

Incandescent Lighting Upgrades

- *Verify appropriate application of compact fluorescent lamps.* These lamps are not as effective projecting light over a distance, since compact fluorescents are not point sources like incandescent and HID lamps. Therefore, these lamps may not be suitable for high ceilings (higher than 15 feet), downlighting applications, or where tight control of the beam spread is necessary.

- *Verify adequate space for Compact Fluorescents.* These lamps are generally longer and wider at the base than the incandescents they replace. Verify that the existing fixture can accommodate the specified compact fluorescent, noting that a variety of compact fluorescent configurations are available.

- *Verify applicability with manufacturers' specifications.* Lamp light output may be adversely affected by high temperatures created by heat trapped near the lamp, by cold ambient temperatures, and by inappropriate lamp orientation. Typically, the light output for "base-down" orientation is as much as 15 percent less than with "base-up" operation. Some compact fluorescents have difficulty starting when ambient temperatures drop below 40°F, although lamps are available which are designed to start at temperatures below freezing. Some systems with electronic ballasts may be incompatible with occupancy sensors that utilize solid-state switches instead of air-gap switches or relays (unless a ground wire is available). Contact the manufacturer of the occupancy sensor to confirm compatibility.

- *Application of compact halogen lamps.* Due to their lower efficacy, these lamps should not be used where compact fluorescents would serve satisfactorily.

- *Application of exit sign upgrades.* Check with local building codes for accepted emergency exit sign illuminance options and accepted retrofit sources. Some new or retrofit exit sign lighting technologies may not produce the required brightness during the life of the source. Verify that your new exit sign complies with UL 924 standards and that your retrofit illumination sources are UL-listed for use in your exit sign. Use only UL-classified retrofit kits that are designed for your specific exit sign.

High Intensity Discharge Lighting Upgrades

- *Application of HID retrofits.* All HID lamps require warm-up and restrike periods, so frequent switching applications should not use these lamps. Using occupancy sensors with HID lighting is also inadvisable.

- *Conversion to high-efficiency HID systems.* Selection of HID fixtures should be based on the following criteria that pertain to the task: color rendering quality, efficiency, lamp life, lumen maintenance, and light distribution. The retrofit, if a new layout is proposed, may require modification of the wiring in the space. The practicability and cost of rewiring should be addressed in the qualification of this retrofit.

- *Reduced-wattage HID systems.* In most cases, a reduced-wattage energy-saver metal halide or high-pressure sodium lamp will also cause a corresponding reduction in light output. A simple trial installation is recommended in order to compare the light output and quality of these new lamps. Also, make sure that any retrofit lamp under consideration is UL-listed.

Occupancy Sensor Installation

- *Use a qualified professional.* Occupancy sensors, when properly specified, installed, and adjusted should provide reliable operation of lighting systems during periods of occupancy and should not disrupt normal plant operations. Most cases of failed occupancy sensor installations can be linked to improper product selection or placement. The specification and placement of occupancy sensors should be performed by an experienced professional to ensure adequate occupancy sensing coverage.

- *Provide for tuning and adjustment of sensors.* Systems must be tuned after installation by adjusting the time delay and sensitivity as appropriate for the space. Most suppliers offer this post-installation service. As part of your agreement with your supplier, require a maximum 24-hour response time to address occupant complaints that may arise after the sensors have been installed and tuned. In some cases, the placement of sensors may need to be adjusted to provide reliable coverage.

- *Select products with adequate coverage areas.* Designers should pay particular attention to the coverage area which defines the physical limits of the sensor's ability to detect motion. Most manufacturers publish their coverage areas for the maximum sensitivity setting, although this may not be clearly stated in the product literature. In some cases, more than one occupancy sensor may be required in a space to extend the coverage area, as in the case of a large office area.

- *Design sensor installation to avoid false activation.* Both infrared and ultrasonic sensors are susceptible to activation by false signals. Ultrasonic sensors can be activated by vibrations as light as those caused by an air conditioner starting, or by moving air. Ultrasonic sensors should not be used in areas where strong air currents exist, and ceiling-mounted units should be located away from ventilation diffusers. Infrared sensors may be located in positions that allow the sensor to have line-of-sight into an adjacent corridor which could keep lights on unnecessarily. By applying masking material to the appropriate facets of the PIR sensor's lens, this potential problem can be avoided. In addition, a mirrored image or direct sunlight may provide a signal to the PIR sensor that a space is occupied.

- *Verify sensor compatibility with electronic ballasts.* Mechanical relays typically used in older technology occupancy sensors may become damaged by the relatively high in-rush currents that result when an occupancy sensor makes and breaks the electrical contact in electronically ballasted fluorescent systems. Contact the manufacturer to verify that the sensor is compatible with electronic ballasts.

- *For large projects, conduct a trial installation and evaluate sensor performance.* Not all sensors perform comparably. Before purchasing a specific name brand of sensor, conduct a simple, simultaneous trial installation of all products under consideration. Follow this test procedure:

1. Install ceiling-mounted sensors temporarily in a strategic location as suggested by the sensing coverage pattern.

2. Connect these sensors to a power supply. They should not, however, be connected to the lighting circuit.

3. Notice the LED indicator light that illuminates when the sensor detects motion. At various locations in the test room, perform several types of motions, varying the magnitude, speed, and direction of motion. Also, include a test that evaluates the sensor's ability to detect motion behind obstacles.

4. Note which sensors were most successful in detecting minor motion (both with and without obstacles), as well as which sensors were most affected by false signals.

Scheduling Controls Installation

- *Application of time-switching systems.* Twenty-four-hour emergency lighting should be provided in areas with sweep systems to provide safe access to lighting control override switches.

- *Application of daylight switching systems.* Mechanical time clocks are not recommended for daylighting switching control because they can be relatively inaccurate in scheduling on/off functions, and may get off schedule if not properly maintained. Daylight switching indoors has been applied with varying degrees of success. In relatively low mounting heights, users may object to the use of automatic switching of the lighting system during daylight hours because it draws attention to sudden changes in illumination. However, adverse occupant reactions can be minimized if the sensor can be programmed to turn on the lights when the ambient light level drops to about 30 footcandles, and turn off the lights when the ambient light level climbs to about 65 footcandles. Still, the most successful indoor applications for daylighting control usually involve dimming instead of switching. Some occupancy sensors provide daylight switching control in conjunction with their occupancy switching control. A trial installation is recommended to assess user acceptance of this technology.

Installation and Start-Up

- *Perform start-up immediately upon completion of the light fixture or controls modifications in a plant area.* Implement final adjustments, calibration, and installation check, including measurement of light levels, and "walk-test" occupancy sensor operation in the presence of the agency's designated representative(s). For lighting level measurements, allow all lamps to "burn-in" for at least 100 hours. When performing walk-tests of occupancy sensor operation, the contractor should provide the services of the manufacturer's representative to confirm the testing and commissioning procedures.

- *Certify completion of the work.* Upon satisfactory completion of installation and start-up, the contractor should submit written reports that verify the results and confirm completion of the work.
- *Provide training for plant staff.* After start-up, the contractor should instruct plant personnel as to the proper operation and maintenance of the lighting system, including troubleshooting, repair and replacement, parts inventory and maintenance record keeping (also see the *Lighting Maintenance* section on page 11-12).
- *Properly dispose of hazardous waste.* Provide for the proper handling and disposal of PCB-containing ballasts and mercury-containing lamps as discussed on page 11–10 of this manual.
- *Provide testing and calibration of daylight switching system components.* Photocells should be properly calibrated and maintained to eliminate wasteful "day-burning."

Follow-Up and Maintenance

- *Perform regular maintenance.* Regularly check adjustment of lighting controls to ensure that controls are functioning properly. If controls are overridden by employees, this may signal improper operation, a need for training on proper use of the controls, or an improper application of the controls. At least once a year, clean lighting fixtures (including lenses, lamps and interior reflective surfaces) to maximize light output.
- *Implement a program for continued improvement.* Evaluate savings of installed projects to verify that projected savings have been achieved. Promote communication between plant management and plant operations personnel to encourage identification of additional opportunities for operational improvements. When the use of an office area changes, reevaluate the lighting needs for the space and determine if lighting levels or controls should be adjusted.

References

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2. Adapted from U.S. Environmental Protection Agency (EPA), Global Change Division, 1992. *Green Lights Program Lighting Upgrade Manual*, 2d ed., EPA, Washington, DC.

Additional Resources

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- U.S. Environmental Protection Agency Regional Office, Toxic Substances Control Act (TSCA) Assistance Information Hotline: (202) 554-1404.

Lighting Retrofit Checklist

Predesign

- ❑ Assess required level of expertise.
- ❑ Confirm assumptions and benefits.
- ❑ Specify target illumination levels.
- ❑ Coordinate construction/operation.
- ❑ Include maintenance needs.
- ❑ Specify applicable location for lighting controls.
- ❑ Determine type of lighting to install.
- ❑ Assess potential for harmonic distortion.

Design and Equipment Selection

Fluorescent Lighting Upgrades:

- ❑ Select proper lamps and ballasts for each application.
- ❑ Check system compatibility.
- ❑ Determine tandem wiring requirements.
- ❑ Consider compact fluorescent task lighting.

Fixture Upgrades:

- ❑ Evaluate possibility of delamping while maintaining target light levels.
- ❑ Evaluate the effectiveness of retrofitting reflectors.
- ❑ Specify most efficient lens/louver configuration.
- ❑ Specify appropriate selection and installation of new energy-efficient fixtures.
- ❑ Specify appropriate implementation of deep-cell parabolic fixtures. Guard against undesired wall-shadowing.

Incandescent Lighting Upgrades:

- ❑ Verify appropriate application of compact fluorescent lamps.
- ❑ Verify adequate space for compact fluorescents.
- ❑ Verify applicability with manufacturers' specifications.
- ❑ Consider compact fluorescents prior to specifying compact halogen lamps.
- ❑ Verify compliance with local building codes for exit sign retrofit kits.

High Intensity Discharge Lighting Upgrades:

- ❑ Specify application of HID retrofits. Avoid applications with frequent switching, such as with occupancy sensor controls.
- ❑ For reduced-wattage HID systems, verify that target light levels will be met.

Occupancy Sensor Installations:

- ❑ Use professional services.
- ❑ Provide for tuning and adjustment of sensors.
- ❑ Select products with adequate coverage areas.
- ❑ Design sensor installation to avoid false activation.
- ❑ Verify compatibility with electronic ballasts.
- ❑ For large projects, conduct a trial installation and evaluate the sensor's performance.

Scheduling Controls Installations:

- ❑ Specify application of time-switched systems.
- ❑ Specify application of daylight switching systems.

Installation and Start-Up

- ❑ Perform start-up immediately upon completion of the light fixture or controls modifications in a plant area.
- ❑ Certify completion of the work.
- ❑ Provide training for plant staff.
- ❑ Dispose of hazardous waste from lighting retrofits in an environmentally responsible manner.
- ❑ Provide testing and calibration of daylight switching system components.

Follow-Up and Maintenance

- ❑ Implement a lighting maintenance program.
- ❑ Implement a program for continued improvement, and monitor monthly billing to calculate savings.

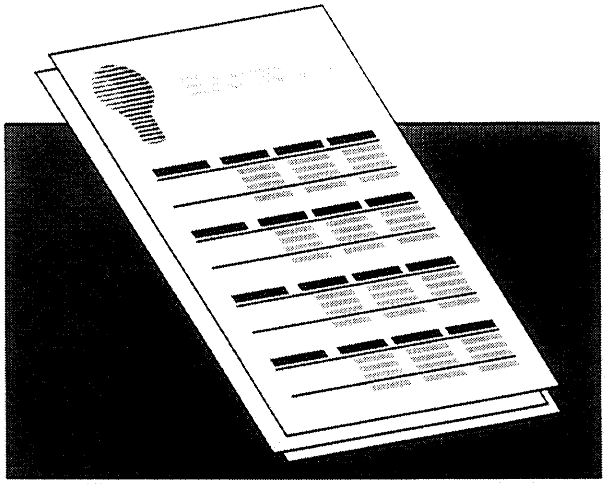
An electronic version of this checklist is available on the *Energy-Water Connection* Web site at ww.energy.ca.gov/water/docs.html or by calling (916) 654-4070. This material will be periodically updated.

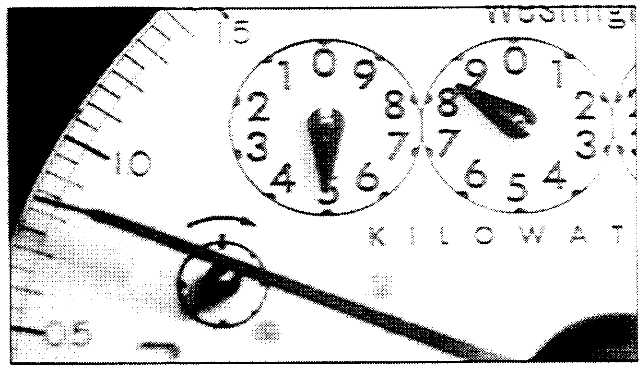
Appendix A: EPRI Brochure: "Reduce Costs by Understanding Your Electric Bill"

Reduce Costs by Understanding Your Electric Bill

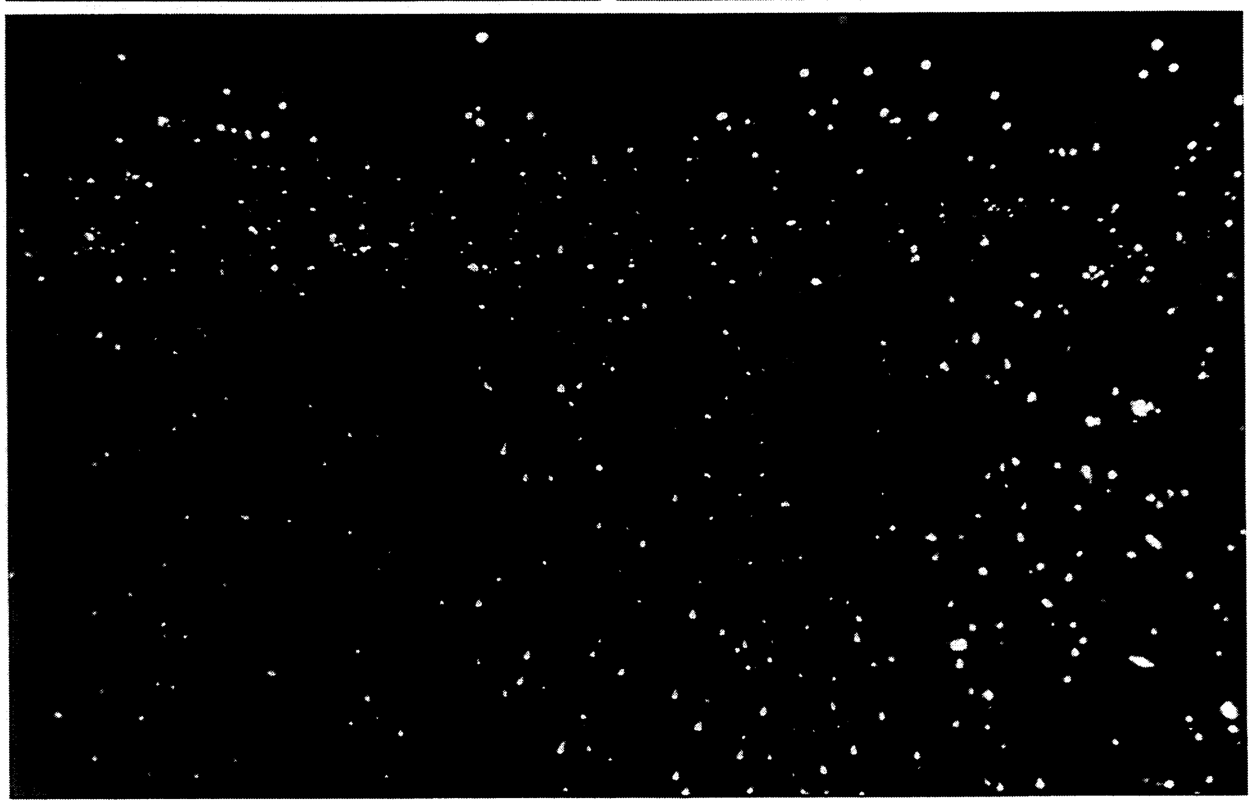
EPRI

Cost-Saving Strategies for Water/Wastewater Plants





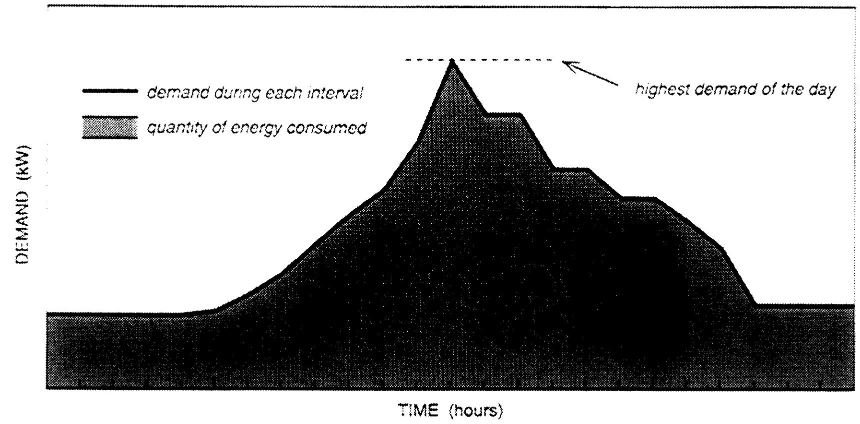
ELECTRIC
POWER
RESEARCH
INSTITUTE



Electricity is typically the most costly item—outside of labor—in the operating budget for water supply and wastewater treatment plants. However, many water/wastewater plant managers have found they can lower their electric bills without compromising service. You may be able to lower your plant's electricity costs by revising operating schedules or methods, replacing inefficient equipment, or selecting a different rate schedule.

Understanding how the electric utility computes your bill is an important step in lowering your electricity costs.

Electricity Use Profile (sample)



Energy *(kWh) is the quantity of electricity used.* ***Demand*** *(kW) is the peak rate at which electricity is used, measured within short intervals (15 or 30 minutes).*

BASIC BILLING CONCEPTS

Two major kinds of charges appear on your electric bill. Electric utilities measure the quantity (kWh) of electricity supplied, which is the "**energy**" component of the bill. They also measure the power (kW) supplied, which is the "**demand**" component of the bill.

Electric utilities invest in generating and distribution equipment to supply the power you need when you need it. Because electricity (unlike water) is not easily stored, it is generated as it is needed. Electric utilities must therefore have adequate capacity to satisfy their customers' maximum requirements—both for quantity (kWh) and for power level (kW). Electric rates are set to cover the total costs of providing electricity.

Electric bills can be complex, and one power company's bills can look very different from another's. Yet, the charges on even the most complicated bills can usually be separated into "energy" and "demand."

Electric utilities offer different **rate schedules** for different classes of customers. For example, residential customers usually pay a higher energy rate but are not billed separately for demand. Large commercial and industrial customers may have a choice between several rates. Some water/wastewater facilities have found substantial savings simply by selecting a rate schedule that better fits their pattern of electricity use.

Your electric utility account representative can provide you with printed rate schedules describing the various rates available and how charges are calculated. Most electric utilities are willing to change a customer's rate schedule free of charge.

ENERGY (kWh)

Of all the charges on your electric bill, energy—the quantity of electricity supplied—is the most straightforward. Energy is measured in kilowatt hours (kWh). The longer a pump runs, the more kWh it uses. Typical costs range from 4¢ to 12¢ per kWh.

It is a good idea to know how much energy the various motors in your plant use. To calculate a motor's energy use, multiply its horsepower by the standard conversion factor (1 hp = 746 W) and by run-time, and then divide by the motor's efficiency. The following example shows the calculation for a 92% efficient fully-loaded 100 hp motor running twenty-four hours a day, for thirty days. Cost is figured at 8¢/kWh.

ENERGY USE:

$$\frac{\text{hp} \times 0.746 \text{ kW/hp} \times \text{hrs} \times \text{days}}{\text{motor efficiency (\%)}} = \text{monthly kWh}$$

$$\frac{100 \times 0.746 \times 24 \times 30}{0.92} = 58{,}383 \text{ kWh}$$

ENERGY COST:

$$58{,}383 \text{ kWh} \times \$0.08/\text{kWh} = \$4{,}671$$

COST-$AVING TIPS:
Pump energy depends on pump efficiency, flow, and head. Review specifications of pumps and test their efficiency. You can then figure out the relative performance of different pumps in the same service.

For each combination of flow and pressure that your system requires, select the most efficient pump. Use adjustable speed drives on pumps with variable loads.

Fuel Adjustment Charge

Many electric utilities have a fuel adjustment charge, based on the current month's cost of fuel. It typically appears on the bill as a charge of 1¢ to 5¢ per kWh. If fuel costs have decreased since the rate was set, the charge appears as a credit on the bill.

DEMAND (kW)

Demand—the maximum rate at which electricity is used—is measured in kilowatts (kW). Electric utilities charge from $1 to $25 per kW per month for demand.

Meters record your greatest power demand in 15-minute or 30-minute intervals. Your demand charge is based on the highest-demand interval each month. (Short periods of intense use, such as the ten-second start-up of a motor, have little or no effect on demand.)

You may be able to reduce your demand cost by changing when you run intermittently operated motors, drives, etc. Let's say you have two pumps that each draw 25 kW and run for two hours each day. If they run at the same time, their contribution to demand is 50 kW. But if they are run at different times, their demand is only 25 kW, and you pay only half as much demand charge for them.

The following sample calculation shows that a 92% efficient fully-loaded 100 hp motor draws about 81 kW. The demand rate in this example is $10/kW.

DEMAND:

$$\frac{\text{hp} \times 0.746 \text{ kW/hp}}{\text{motor efficiency (\%)}} = \text{kW}$$

$$\frac{100 \times 0.746}{0.92} = 81.09 \text{ kW}$$

DEMAND COST:

$$81.09 \text{ kW} \times \$10/\text{kW} = \$810.90$$

COST-$AVING TIPS:
Eliminate spikes in your facility's demand. During periods of high energy use, avoid running large intermittent pumps when the main pumps are operating. Operate smaller pumps when the system is drawing its maximum electrical load. Use system storage to ride out periods of highest load rather than operating additional pumps.

Ratchet Charge

Some electric utilities have a "ratchet clause" in the rate schedule. This clause charges the customer for a percentage of either (1) the maximum demand during the previous eleven months, or (2) the maximum demand during the previous summer months. Remember, the electric utility carries a large financial burden for its capacity. Perhaps your plant did not use much power in the present month. But the electric utility needs adequate capacity to meet your maximum demand—and it must maintain that capacity during all twelve months of the year.

COST-$AVING TIPS:
Reduce ratchet charges by reducing your maximum demand. Watch the use of large pumps and compressors that are needed only occasionally. Avoid operating them at the same time.

Carefully plan when to operate large plant equipment in the months of your greatest electric demand, in order to keep monthly demands as level as possible. The more level your month-to-month demand, the closer you will come to paying only for actual demand each month.

"Power Factor," "Reactive Power," "kVAR"

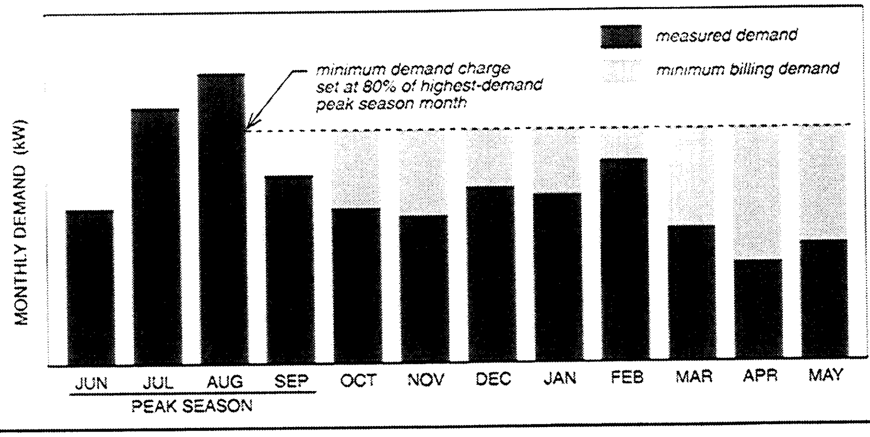
Motors (and also magnetic lighting ballasts, transformers, and some other equipment) draw two kinds of current. One kind is the electrical current converted by the motor to useful power. The other is magnetizing current that carries no "energy" with it, but is needed to make the motor operate.

Power factor is a measure of how effectively the current delivered to the motor is converted into useful energy, and is shown as a percentage. Many electric utilities charge extra for low power factor, on the grounds that it costs the utility more to build and operate the additional equipment that carries this extra current.

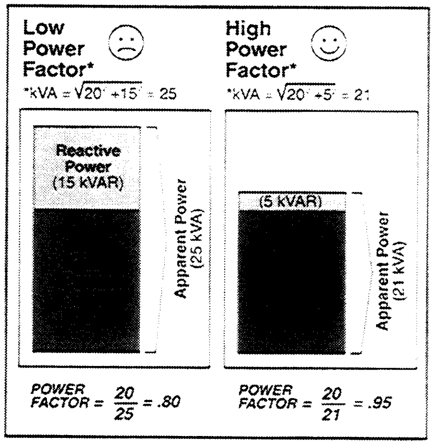
On your bill the charge for power factor may appear as a "power factor charge," a "reactive power charge," or a "kVAR charge." Some electric utilities combine the charge for power factor with the demand charge, and on the bill show both charges as a single "kVA demand charge." Regardless of what it is called, if you have poor power factor, you are probably being billed for it.

Power factor reflects the extent that current and voltage cycle in

Ratchet Charges (sample)



Some utilities use ratchet charges to bill customers all year long for maximum demand set in a single month. In this example, demand charges are based on actual demand during the four summer months. During the remaining eight months, however—no matter how low their measured level of demand—the demand charges are based on a fixed minimum billing demand, in this case 80% of the highest measured demand during the preceding summer months.



*The effect of magnetizing current is measured in units of kVAR (kilovolt amperes reactive) and is called "**reactive power**." "**Apparent power**," which is measured in kilovolt amperes (kVA), is calculated by multiplying the electric current by the voltage. "**Real power**," which is the same as demand kilowatts (kW), is the power actually delivered to your equipment. **Power factor** is calculated by dividing "real power" by "apparent power."*

phase. The best—most efficient—power factor is 100%, which occurs when current and voltage are perfectly in phase. When they are out of phase, the current flow is greater than necessary. In electric resistance heating, for example, current and voltage are perfectly in phase. Electric resistance heating uses no reactive power and so has a power factor of 100%. A partly loaded motor, on the other hand, does draw reactive power and may have a power factor of 50% or even less. A motor's power factor can be improved by installing a capacitor in parallel.

In water/wastewater plants, motors running less than fully loaded are the major contributors to poor power factor (and to power factor charges).

COST-$AVING TIPS:
To reduce power factor charges, install capacitors in parallel with low-load motors. When replacing motors, buy high-efficiency, correctly sized motors to save energy and improve power factor.

OPTIONAL RATE SCHEDULES

Many electric utilities charge more for electricity used when their own costs are the greatest. Your power company probably owns many generating plants, and these plants vary in efficiency, fuel type, and operating costs. For its routine electricity production, the power company relies on its most economical plants. The other plants are used only as necessary to supplement these main plants in times of high demand. For example, on summer afternoons when many customers are using air conditioning, the power company may need to run all of its generating plants—including the less economical ones. It might even need to purchase yet more expensive energy from other companies. The power company charges more for electricity used during peak hours because this electricity is more expensive to produce.

Electric utilities have devised a number of alternative rate schedules, some of which are discussed below. These rates are designed to encourage customers to reduce their electricity requirements during peak hours.

Time-of-Use Rates

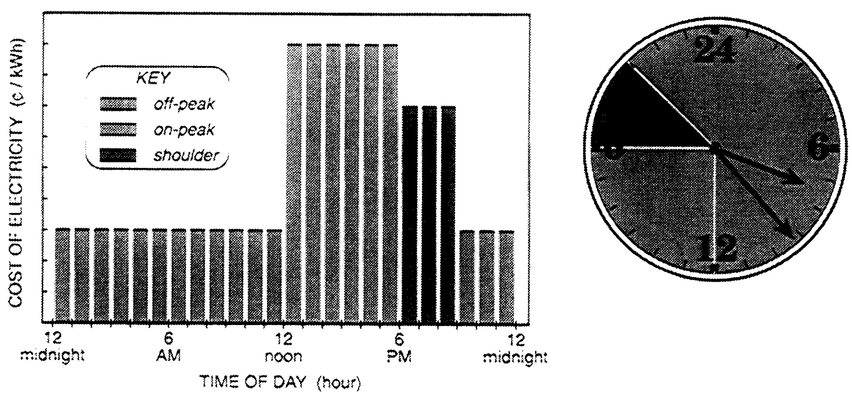
By charging more during the peak period, when incremental costs are highest, these rates send accurate marginal-cost price signals to customers. Periods of heavy electricity use are typically defined as "on-peak" hours; periods of lower use are "shoulder" or "mid-peak" hours, and times of lowest use "off-peak." The difference in energy charges between on-peak and off-peak times might be as much as 6¢/kWh.

Similarly, your demand charges may be computed at a much higher rate if your highest-demand interval occurs during the "on-peak" hours.

COST-$AVING TIPS:
If you are on a time-of-use rate, minimize pumping during on-peak periods. See whether you can take advantage of storage in the water supply or collection system. Your plant might be able to operate some pumps at night rather than during the day. The electric bill for processing the same quantity of water could then be reduced.

If your facility is not on a time-of-use rate, find out whether your electric utility offers such rates. You may be able to reduce costs by switching to time-of-use rates.

Time-of-Use Billing Chart (sample)



This chart shows the rate charged for electricity during each hour of the day. The face of the corresponding 24-hour clock is colored red and green for the most expensive and least expensive times for electricity use. You may want to prepare such a clock—representing your own electric utility's time-of-use billing periods—and hang it in a highly visible location as a guide for plant operators.

Interruptible, Curtailment, and Customer Generator Rates

It is important to electric utilities to minimize overall system loads during periods of peak electric demand. Building new generating and distribution facilities is very expensive. The electric utility therefore offers reduced rates to large customers who help them avoid the need for new facilities. Upon request from the electric utility, these customers lower their demand. They can do this by turning off some or all of their large electrically driven equipment. Or, they can use emergency generators or engine-driven pumps instead of utility-supplied power. If, like many water/wastewater plants, you already have an emergency generator installed to provide power in an emergency, the generator can be used to reduce electric demand.

To obtain interruptible, curtailment, or customer generator rates, the customer makes a long-term agreement with the power company—usually for five years. The customer promises to interrupt or reduce plant loads at the request of the power company during the occasional times of peak demand. In return, the power company applies lower rates to the demand charge on the bill for the duration of the agreement. Some power companies send end-of-season checks to reward customers that have responded according to the contract. Penalties for nonconformance, however, are high. Failure to live up to the agreement could increase a customer's demand charge for the life of the contract.

COST-$AVING TIPS:
Find out whether your electric utility offers "interruptible," "curtailment," or "customer generator" rates. If you are thinking of using an emergency generator on a regular basis, analyze operating conditions as well as your ability to maintain the generator. Talk with your account rep about a load management agreement.

HOW YOUR ELECTRIC COMPANY CAN HELP

Your account representative can explain how your actual electric use affects your bills. With a thorough understanding of your costs, you can take steps to reduce them. Take the time to get to know your account rep. Be sure that you have a copy of your current contract(s) and/or rate schedule(s). Ask your account rep to help you answer the following questions.

☞ What other electric rates are available for the plant? Would they be less costly?

☞ What are the months in the power company's "peak season?"

☞ Daily billing time of use, peak season (weekdays):

PEAK: ____AM/PM to ____AM/PM

SHOULDER: ____AM/PM to ____AM/PM

OFF-PEAK: ____AM/PM to ____AM/PM

☞ Is there a ratchet clause? What percentage is charged? Which months in the past year were affected by the ratchet clause? What was the additional annual cost?

☞ What was the peak month kW demand? How much lower would it need to be to eliminate ratchet charges in the future?

☞ Are there any power factor penalties in effect for this plant? What is the annual cost?

☞ What is the weekly demand profile in four seasons? Are there opportunities to reduce peak demand or to shift load to off-peak periods?

☞ Is a "customer generator" or other load management rate available? What are the requirements? What are the benefits?

☞ How much do you spend for electricity to run specific pumps in your plant? Calculate energy (kWh) and demand (kW) costs for various motors using the equations provided earlier in this brochure.

Reading Your Facility's Electric Bill

Even if you understand the kinds of charges on your electric bill, you may still find the bill puzzling. Electric bills often use abbreviations and codes that are not explained. Take the time to understand each code and see how the charges are combined to calculate the billing amount for a single month. You will then find it easier to understand future bills.

Ask your electric utility account representative for help. Meet for an hour or so to get a complete explanation of each item used to compute the bill. Some items will be shown directly on the bill while others will not. You can use the following checklist as a starting point for a reference sheet. Annotate your bill by writing the number corresponding to each reference list item directly on the bill where the item appears.

Use your annotated bill, your reference sheet, and your rate schedule(s) and contract(s) to interpret future bills.

Reference Checklist for Coding Your Electric Bill

Use this checklist for identifying items on a sample electric bill. An annotated sample bill can help you interpret later bills.

1. Rate schedule: identification of formulas by which a bill is calculated.
2. Meter reading at start of period.
3. Meter reading at end of period.
4. Multiplier: this constant is multiplied by the difference between the meter readings to calculate kilowatt hours.

5. Kilowatt hours (kWh) *(in each category: on-peak, off-peak, shoulder, etc.).*
6. Cost per kilowatt hour (kWh) *(in each category: on-peak, off-peak, shoulder, etc.).*
7. Kilowatt hour charge *(in each category: on-peak, off-peak, shoulder, etc.).* This charge is the kilowatt hours multiplied by cost per kWh in each billing category.
8. Actual peak kW demand: "real power" measured by meter.
9. Actual peak kVA: "apparent power" measured by meter.
10. Billing demand (includes adjustments for poor power factor, ratchet clause, and others).
11. Cost per unit of billing demand.
12. Billing demand charge: billing demand multiplied by cost per unit.
13. Fuel cost adjustment per kWh: may change monthly according to current cost of fuel; may be positive or negative.
14. Total fuel cost adjustment: total kWh times cost adjustment per kWh.
15. Basic service charge: basic charge to keep account open.

In addition, your bill may have some of the following charges and credits. If so, identify them as well.

- ○ Power factor charge (if separate from billing demand)
- ○ Minimum and maximum charges
- ○ Finance charges and interest on deposit
- ○ Transformer, voltage, or other credits
- ○ Surcharges and taxes
- ○ *Other:* ____________

✓ Checklist for Electricity Cost Savings

- ☐ Compare rate schedules and use the one best suited for your operation.
- ☐ Train operators and maintenance workers to be aware of the time of day for utility on-peak charges. Run motors and other electric loads off-peak whenever possible.
- ☐ Analyze relative efficiency (kWh or $ per million gallons) of major pumps serving the same function. Operate the most efficient pumps.
- ☐ Periodically perform pump efficiency tests to identify maintenance requirements.
- ☐ Use premium high-efficiency motors on fixed speed pumps over 1 hp.
- ☐ Use adjustable speed drives on pumps with variable loads.
- ☐ Avoid periodic motor testing during peak hours.
- ☐ Install capacitors to reduce power factor charges.
- ☐ Use standby generators to reduce peak demand.
- ☐ Install high efficiency lighting systems.
- ☐ In wastewater treatment, convert to efficient air diffusers (fine bubble instead of coarse).
- ☐ In wastewater treatment, use automatic methods for dissolved oxygen control.
- ☐ In water supply systems, increase storage during off-peak periods. Deplete storage during on-peak periods.
- ☐ In water filtration plants, turn off one pump while operating another large pump for a short period. For example, turn off the main supply pump while using backwash pumps or sludge scrapers. Alternatively, backwash during off-peak periods. You will lower the peak demand and reduce your demand charges.

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Electric Power Research Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

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This brochure has been prepared in cooperation with EPRI's Community Environmental Center, located at Washington University in St. Louis, Missouri.

Printed with soya inks on recycled paper (50% recycled fiber, including 10% postconsumer waste) in the United States of America

BR-103303R1

Glossary

ac: Alternating current.

Adjustable-Speed Drive (ASD): Electrical or mechanical equipment used to vary the rotational speed of motors or other equipment.

Alpha Factor: A correction factor used in the design of aeration systems. It is the ratio of oxygen's mass transfer coefficient in clean water to that in dirty water.

Ballast Factor (BF): The ballast factor for a specific lamp-ballast combination represents the percentage of the rated lamp lumens that will be produced by the combination.

Best Efficiency Point (BEP): The rated capacity of a pump, which occurs at the highest efficiency.

Capacitor Switching: Refers to the connection or disconnection of a capacitor bank in an electric utility's distribution system.

Coefficient of Utilization (CU): The ratio of lumens from a luminaire on the work plane to the lumens produced by lamps alone.

Cogeneration: The sequential generation of power with recovery of the waste heat produced by the power generating system.

Color Rendering Index (CRI): A scale of the effect of a light source on the color appearance of an object, compared to its color appearance under a reference light source. This is expressed on a scale of 1 to 100, where 100 indicates no color shift. A low CRI rating suggests that the colors of objects will appear unnatural under that particular light source.

Compact Fluorescent: A small fluorescent lamp that is often used as an alternative to incandescent lighting. The lamp life is about 10 times longer than incandescent lamps and is 3–4 times more efficacious. Also called PL, Twin-Tube, CFL, or BIAX lamps.

Commissioning: The start-up and testing procedures for newly installed equipment. This includes activities such as debugging software and calibrating/balancing instruments.

Constant Wattage (CW) Ballast: A premium type of HID ballast in which the primary and secondary coils are isolated. It is considered a high-performance, high-loss ballast featuring excellent output regulation.

Constant Wattage Autotransformer (CWA) Ballast: A popular type of HID ballast in which the primary and secondary coils are electrically connected. Considered an appropriate balance between cost and performance.

Contrast: The relationship between the luminance of an object and its background.

CRI: (See Color Rendering Index).

Critical Speed: The operating speed of a piece of equipment that produces unacceptable vibration.

Cut-Off Angle: The angle from a fixture's vertical axis at which a reflector, louver, or other shielding device cuts off direct visibility of a lamp. It is the complementary angle of the shielding angle.

Daylight Compensation: A dimming system controlled by a photocell that reduces the output of the lamps when daylight is present. As daylight levels increase, lamp intensity decreases. An energy-saving technique used in areas with significant daylight contribution.

dc: Direct current.

Demand-Side Management (DSM): Balancing supply and demand of electrical energy by controlling and reducing consumption, rather than increasing supply by building new generation facilities. DSM is now referred to simply as *Energy Management.*

Diffuse: Term describing dispersed light distribution. Refers to the scattering or softening of light after reflecting from a luminous surface. (See Specular).

Diffuser (for aeration): Diffusers are devices mounted to the air piping that introduce bubbles of air into the wastewater.

Diffuser (for lighting): A translucent piece of glass of plastic sheet that shields the light source in a fixture. The light transmitted throughout the diffuser will be redirected and scattered.

Direct Glare: Glare produced by a direct view of light sources. Often the result of insufficiently shielded light sources.

Dissolved Oxygen (DO): The amount of oxygen in the wastewater, measured in milligrams per liter (parts-per-million).

DO Probe: An instrument that measures the amount of dissolved oxygen in the wastewater.

Downlight: A type of ceiling luminaire, usually fully recessed, where most of the light is directed downward. May feature an open reflector and/or shielding device.

Efficacy: A metric used to compare light output to energy consumption. Efficacy is similar to efficiency, but is expressed in dissimilar units—lumens per watt. For example, if a 100-watt source produces 9000 lumens, then the efficacy is 90 lumens per watt.

Electronic Ballast: A ballast that uses semiconductor components to increase the frequency of fluorescent lamp operation (typically in the 20–40 kHz range). Smaller inductive components provide the lamp current control. Fluorescent system efficiency is increased due to high-frequency lamp operation.

Electronic Dimming Ballast: A variable output electronic fluorescent ballast.

EMI: Abbreviation for electromagnetic interference. High-frequency interference (electrical noise) caused by electronic components or fluorescent lamps that interferes with the operation of electrical equipment. EMI is measured in microvolts, and can be controlled by filters. Because EMI can interfere with communication devices, the Federal Communication Commission (FCC) has established limits for EMI.

Energy-Efficient Motor: A motor constructed differently than a standard motor to achieve higher efficiency. Efficiency standards are defined by NEMA.

Energy-Saving Ballast: A type of magnetic ballast designed so that the components operate more efficiently, cooler, and longer than a "standard magnetic" ballast. By U.S. law, standard magnetic ballasts can no longer by manufactured.

Energy-Saving Lamp: A lower-wattage lamp, generally producing fewer lumens.

EPACT: Energy Policy Act of 1992. It set minimum efficiencies for selected motors sold in the United States.

FC: (See Footcandle).

Feasibility Analysis: Planning level study, such as an energy assessment, that identifies energy conservation retrofit projects. The analysis usually documents costs and savings for the recommended projects.

Fine Bubble Diffusers: Devices that introduce oxygen into wastewater with very small bubbles which, due to increased surface area, improve the oxygen transfer efficiency.

***Flow Equalization*:** A process in which the variations in flow rate are dampened to produce a constant flow rate.

Fluorescent Lamp: A lamp consisting of a tube filled with argon, along with krypton or other inert gas. When electrical current is applied, the resulting arc emits ultraviolet radiation that excites the phosphors inside the lamp wall, causing them to radiate visible light.

Footcandle (FC): The English unit of measurement of the illuminance (or light level) on a surface. One footcandle is equal to one lumen per square foot.

Fouling Factor: A correction factor used in designing aeration systems that accounts for the effects of fouling on the diffusers.

Glare: The effect of brightness or differences in brightness within the visual field sufficiently high to cause annoyance, discomfort, or loss of visual performance.

Halogen: (See Tungsten Halogen Lamp).

Harmonics: A frequency that is an integral multiple of the fundamental 60-Hz frequency supplied by the electrical utility.

Harmonic Distortion: A sinusoidal component of a periodic wave having a frequency that is a multiple of the fundamental frequency. Harmonic distortion from lighting equipment can interfere with other appliances and the operation of electric power networks. The total harmonic distortion (THD) is usually expressed as a percentage of the fundamental line current. THD for 4-foot fluorescent ballasts usually ranges from 20–40%. For compact fluorescent ballasts, THD levels greater than 50% are not uncommon.

HID: Abbreviation for high intensity discharge. Generic term describing mercury vapor, metal halide, high pressure sodium, and (informally) low pressure sodium lamps and luminaires.

High-Bay: Pertains to the type of lighting in an industrial application where the ceiling is 20 feet or higher. Also describes the application itself.

High Output (HO): A lamp or ballast designed to operate at high current (800 mA) and produce more light.

High Power Factor: A ballast with a rated power factor of 0.9 or higher, which is achieved by using a capacitor. (See NPF).

High Pressure Sodium Lamp: An HID lamp whose light is produced by radiation from sodium vapor and mercury.

Hot Restart or Hot Restrike: The phenomenon of re-striking the arc in an HID light source after a momentary power loss. Hot restart occurs when the arc tube has cooled a sufficient amount.

IES: Illuminating Engineering Society of North America.

Illuminance: A photometric term that quantifies light incident on a surface or plane. Illuminance is commonly called light level. It is expressed as lumens per square foot (footcandles), or lumens per square meter (lux).

Indirect Glare: Glare produced from a reflective surface.

Input/Output (I/O): Interface between the field transmitters and the programmable logic controllers.

Instant Start: A fluorescent circuit that ignites the lamp instantly with a very high starting voltage from the ballast. Instant start lamps have single-pin bases.

Internal combustion: A combustion process that occurs within the cylinders of an engine.

Kilovolt-Ampere: A measure of total electrical power.

kVa (See Kilovolt-Ampere).

LED: Abbreviation for light-emitting diode. An low-wattage illumination technology with a rated life of greater than 80 years. Often used for exit signs.

Lens: Transparent or translucent medium that alters the directional characteristics of light passing through it. Usually made of glass or acrylic.

Light Loss Factor (LLF): A number of elements contribute to a system's LLF. These are factors that allow for a lighting system's operation at less than initial conditions, and they are used to calculate maintained light levels. LLFs are divided into two categories: recoverable and non-recoverable. Examples are lamp lumen depreciation and luminaire surface depreciation.

Life-Cycle Cost: The total costs associated with purchasing, operating, and maintaining a system over the life of that system.

Load Factor: A measure of how effectively a facility manages electrical demand, expressed as a percentage:

$$\frac{\text{Total energy use (kWh)}}{\text{(24 hrs) x (no. days in period) x (highest kW demand)}}$$

Load Management: The strategy used at a facility to control and schedule the use of electrical energy.

Louver: Grid type of optical assembly used to control light distribution from a fixture. Can range from small-cell plastic to the large-cell anodized aluminum louvers used in parabolic fluorescent fixtures.

Low Power Factor: An uncorrected ballast power factor of less than 0.9 (See NPF).

Low-Pressure Sodium: A low-pressure discharge lamp in which light is produced by radiation from sodium vapor. Considered a monochromatic light source (most colors are rendered as gray).

Low-Voltage Lamp: A lamp (typically compact halogen) that provides both intensity and good color rendition. Lamp operates at 12 V and requires the use of a transformer. Popular lamps are MR-11, MR-16, and PAR-36.

Low-Voltage Switch: A relay (magnetically operated switch) that allows local and remote control of lights, including centralized time clock or computer control.

Lumen: A unit of light flow, or luminous flux. The lumen rating of a lamp is measure of the total light output of the lamp.

Luminaire: The complete lighting unit. Consists of a lamp or lamps and the parts designed to hold the lamps, connect them to a power source, and distribute the light. Also called a *fixture.*

Luminaire Efficiency: The ratio of total lumen output of a luminaire and the lumen output of the lamps, expressed as a percentage. For example, if two luminaires use the same lamps, more light will be emitted from the fixture with the higher efficiency.

Maintained Illuminance: Refers to light levels of a space at other than initial or rated conditions. This terms considers light loss factors such as lamp lumen depreciation, luminaire dirt depreciation, and room surface dirt depreciation.

Master Station: Component SCADA Systems. Consists of one or more computers with operator interface capabilities including keyboard, monitor, printer, hard disk drive, network interface. They are connected to the RTUs by radio, hardwire, microwave, or telephone lines.

MCC: (See Motor Control Center)

Mercury Vapor Lamp: A type of HID lamp that produces light by radiation from mercury vapor. Emits a blue-green light. Available in clear and phosphor-coated lamps.

Metal Halide: A type of HID lamp that produces most of its light from radiation of metal halide and mercury vapors in the arc tube. Available in clear and phosphor-coated lamps.

Motor Control Center: Panel containing grouped motor controls.

MR-16: A low-voltage quartz reflector lamp, only 2" in diameter. Typically the lamp and reflector are one unit, which directs a sharp, precise beam of light.

National Electrical Manufacturers Association (NEMA): Organization that sets manufacturing, configuration, and performance standards for electrical products.

NEMA: (See National Electrical Manufacturers Association).

NEMA 1 Enclosure: An electrical enclosure rated for indoor use in dry, noncorrosive environments.

NEMA 3R Enclosure: An electrical enclosure rated for outdoor use.

NEMA 4X Enclosure: An electrical enclosure rated for corrosive environments.

NPF (Normal Power Factor): A ballast/lamp combination in which no components (e.g. capacitors) have been added to correct the power factor, making it normal (essentially low, typically 0.5 or 50%).

Occupancy Sensor: Control device that turns lights off when the space is unoccupied. May be an ultrasonic, infrared, or other type.

Off-Peak Period: The time of lowest energy use experienced by an electrical utility. This typically happens between 6 p.m. and 6 a.m., Monday through Friday and all day Saturday and Sunday.

On-Peak Period: The time of highest energy use experienced by an electrical utility. This typically happens between 12 p.m. and 6 p.m., Monday through Friday.

Optics: A term referring to the components of a light fixture (such as reflectors, refractors, lenses, louvers) or to the light emitting or light-controlling performance of a fixture.

Oxygen Transfer Efficiency: The percent of oxygen that dissolves in wastewater from the amount supplied.

PAR Lamp: A parabolic aluminized reflector lamp. Includes incandescent, metal halide, or compact fluorescent lamps used to redirect light from the source using a parabolic reflector. Lamps are available with flood or spot distributions.

Parabolic Luminaire: A popular type of fluorescent fixture that has a louver composed of aluminum baffles curved in a parabolic shape. The resultant light distribution provides reduced glare, better light control, and greater aesthetic appeal.

Paracube: A metallic-coated plastic louver made up of small squares. Often used to replace the lens in an installed troffer to enhance its appearance. The paracube is visually comfortable, but the luminaire efficiency is lowered. Also used in rooms with computer screens to reduce glare.

Partial-Peak Period: A rate period used by some electrical utilities in the mid-morning and late afternoon hours, Monday through Friday, when energy consumption is climbing to or decreasing from the daily peak.

Peak Demand: Measured in kilowatts, it is the maximum amount of energy that a utility experiences each day.

Photocell: A light sensing device used to control luminaires and dimmers in response to detected light levels.

Photometric Report: A photometric report is a set of printed data describing the light distribution, efficiency, and zonal lumen output of a luminaire. This report is generated from laboratory testing.

Power Factor: The ratio of total watts to the total root-mean-square (RMS) volt-amperes.

Preheat: A type of ballast/lamp circuit that uses a separate starter to heat up a fluorescent lamp before high voltage is applied to start the lamp.

Prime Mover: An engine or motor that produces usable work.

Programmable Logic Controller (PLC): A programmable microprocessor that controls a process or equipment based on signals received from field transmitters.

Radio Frequency Interference (RFI): Interference to the radio frequency band caused by other high-frequency equipment or devices in the immediate area. Fluorescent lighting systems generate RFI.

Rapid Start (RS): The most popular fluorescent lamp/ballast combination used today. This ballast quickly and efficiently preheats lamp cathodes to start the lamp. Uses a bi-pin base.

RAS: (See Return Activated Sludge).

Recessed: The term used to describe the door frame of a troffer where the lens or louver lies above the surface of the ceiling.

Reflectance: The ratio of light reflected from a surface to the light incident of the surface. Reflectances are often used for lighting calculations. The reflectance of a dark carpet is around 20%, and a clean white wall is roughly 50% to 60%.

Reflector: The part of a light fixture that shrouds the lamps and redirects some light emitted from the lamp.

Refractor: A device used to redirect the light output from a source, primarily by bending the waves of light.

Relay: A device that switches an electrical load on or off based on small changes in current or voltage. Examples: low voltage relay and solid state relay.

Remote Terminal Unit (RTU): A component of a SCADA System used in the field to transmit information to a master station located elsewhere. Some RTUs have programmable logic to allow local control, whereas others merely transmit data.

Resonance: A condition evidenced by a large oscillatory amplitude that results when the frequency of a small amplitude of a periodic input approaches one of the natural frequencies of the driven system.

Return Activated Sludge (RAS): Activated sludge that has flown out of the aeration basin into the secondary clarifier where it is collected at the bottom and returned to the aeration basin. Returning activated sludge maintains the microbiology concentration necessary to obtain the proper level of treatment.

Retrofit: Modification to a facility or process that requires installation of new equipment or modifications to existing equipment.

RMS Current: Root-mean-squared current. The square root of the average of the square of the current taken throughout one period.

Self-Luminous Exit Sign: An illumination technology using phosphor-coated glass tubes filled with radioactive tritium gas. The exit sign uses no electricity.

Semi-Specular: Term describing the light reflection characteristics of a material. Some light is reflected directionally, with some amount of scatter.

Shielding Angle: The angle measured from the ceiling plane to the line of sight where the bare lamp in a luminaire becomes visible. Higher shielding angles reduce direct glare. It is the complementary angle of the cutoff angle (See Cutoff Angle).

Spacing Criterion: A maximum distance that interior fixtures may be spaced that ensures uniform illumination on the work plane. The luminaire height above the work plane multiplied by the spacing criterion equals the center-to-center luminaire spacing.

Specular: The mirrored or polished finish of the material used in some louvers and reflectors. The angle of reflection is equal to the angle of incidence.

Starter: A device used with a ballast to start preheat fluorescent lamps.

State Estimator: A device that checks telemetered data and replaces missing or out-of-scan data.

Stroboscopic Effect: Condition where rotating machinery or other rapidly moving objects appear to be standing still due to the alternating current supplied to light sources. Sometimes called *strobe effect.*

Supervisory Control and Data Acquisition (SCADA) System: Network of computers, controllers, field instruments, software interfaces, and communication devices that allow central monitoring or control of remote equipment or facilities.

System Integrator: Vendor or manufacturer employed to design and program a SCADA system.

Tandem Wiring: A wiring option in which a ballast is shared by two or more luminaires. This reduces labor, materials, and energy costs. Also called "masterslave" wiring.

THD: (See Harmonic Distortion).

Third-Party Engineer: Engineer who is not part of the owner's equipment supplier or installation contractor staff.

Transient Overvoltage: The peak voltage during the transient conditions resulting from the operation of a switching device.

Transient Voltages: A change in the steady-state condition of a voltage, a current, or both.

Transmissivity (of wastewater): The rate at which UV light is transmitted through wastewater.

Troffer: The term used to refer to a recessed fluorescent light fixture (combination of trough and coffer).

Tungsten Halogen Lamp: A gas-filled tungsten filament incandescent lamp with a lamp envelope made of quartz to withstand the high temperature. This lamp contains some halogens (namely iodine, chlorine, bromine, and fluorine), which slow the evaporation of the tungsten. Also commonly called a *quartz lamp*.

Ultraviolet (UV): Invisible radiation that is shorter in wavelength and higher in frequency than visible violet light (literally, beyond the violet light).

Vandal-Resistant: Fixtures with rugged housings, break-resistant type shielding, and tamper-proof screws.

Variable-Frequency Drive (VFD): Electronic device that allows changes in equipment speed by varying the frequency of the electricity supplied to the equipment motor. VFDs are the most common adjustable-speed drive now used at water and wastewater facilities.

VCP: Abbreviation for visual comfort probability. A rating system for evaluating direct discomfort glare. This method is a subjective evaluation of visual comfort expressed as the percent of occupants of space who will be bothered by direct glare. VCP allows for several factors: Luminaire luminances at different angles of view, luminaire size, room size, luminaire mounting height, illuminance, and room surface reflectivity. VCP tables are often provided as part of photometric reports.

Very High Output (VHO): A fluorescent lamp that operates at a very high current (1500 mA), producing more light output than a high output lamp (800 mA) or a standard output lamp (430 mA).

Volt: The standard unit of measurement for electrical potential. It defines the "force" or "pressure" of electricity.

Voltage: The difference in electrical potential between two points of an electrical circuit.

Wallwasher: A luminaire that illuminates vertical surfaces.

Waste Activated Sludge (WAS): The activated sludge removed from the secondary treatment process to control the solids residence time in the aeration basins.

Watt (W): The unit for measuring electrical power. It defines the rate of energy consumption by an electrical device when it is in operation. The energy cost of operating an electrical device is calculated as its wattage times the hours of use. In single-phase circuits, it is related to volts and amps by the formula: Volts x Amps x Power Factor = Watts. (Note: For ac circuits, power factor must be included.)

Wheeling: The function of transporting electric power for a customer from the point of generation to the location of use.

Work Plane: The level at which work is done and at which illuminance is specified and measured. For office applications, this is typically a horizontal plane 30 inches above the floor (desk height).

Target:

Municipal Water and Wastewater

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CR-109081

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com